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AUSTRALIAN SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

ISSUE 88



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How many moons does Earth have? More than one, astronomers are beginning to think. See page 32.

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We're all astronomy educators

I'm writing this editorial in August, a month that I've sort of come to dread, and chances are you know why. It's because of that crazy email that does the rounds every year, claiming that Mars will make a close approach to Earth and appear as large in the sky as the full Moon. I'm sure you've seen it.

All month long I receive phone call after phone call from friends, family, colleagues and the media, all of them wanting to know when and where they can see it. They sound so disappointed when I tell them that it's bogus, and that Mars will not do as advertised and rival the Moon. It's almost as if — oh, I don't know — that they expect everything they see and hear on the Internet to be absolutely correct and infallible. Fancy that.

And then there are the emails regarding a major meteor shower in August. You've probably seen these too, in which it is claimed that you'll be able to spot hundreds of meteors per hour in a once-in-a-lifetime celestial display. Well, it's certainly true that the Perseid meteor shower occurs during this time. And it's also true that this shower often puts on a good show. But not for us in the Southern Hemisphere. The Perseids are a northern sky phenomena; the most we can hope to see are a few stragglers that cross the celestial equator heading south.

The way I see it, it's misinformation like this that gives us the opportunity to engage with our friends and family, set the record straight, and gently educate them about the way the sky really works... especially regarding the size of Mars and the differences between northern and southern skies. We all have a role to play in educating the wider community about the wonders of the cosmos, and what the joy of stargazing is all about.

Jonathan Nally

Editor

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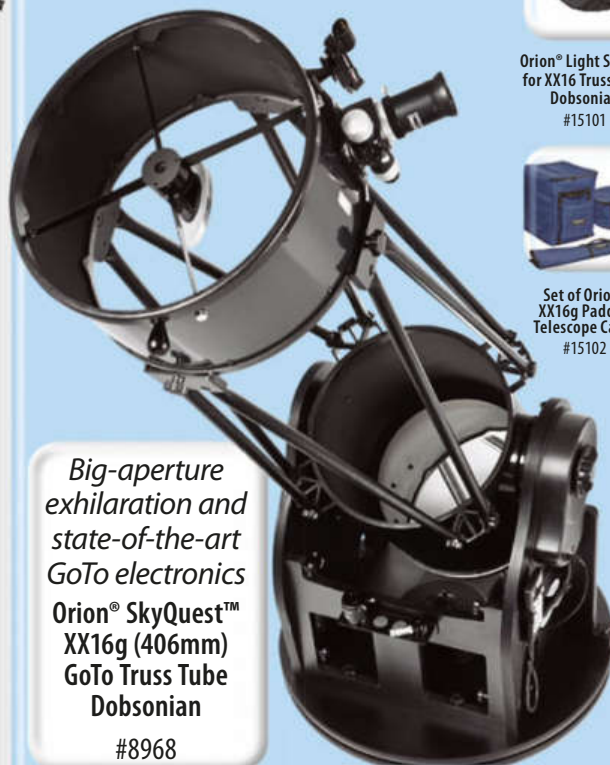


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DARK MATTER

Mapping the (not so) invisible

Two projects are mapping the distribution of dark matter in the universe, probing scales both large and small.

One, the Dark Energy Survey, is tackling the large-scale universe using the Dark Energy Camera, a 570-megapixel CCD camera that's surveying a huge, 5,000-square-degree swath of the southern sky.

Using preliminary data that covers just 3% of the full survey, Vinu Vikram (Argonne National Laboratory) and colleagues examined the shapes of more than 1 million faraway galaxies, whose light has travelled between 5.8 billion and 8.5 billion years to reach us. The team was looking for the smearing effect of intervening dark matter, which acts as a gravitational lens to magnify and distort distant galaxies' light.

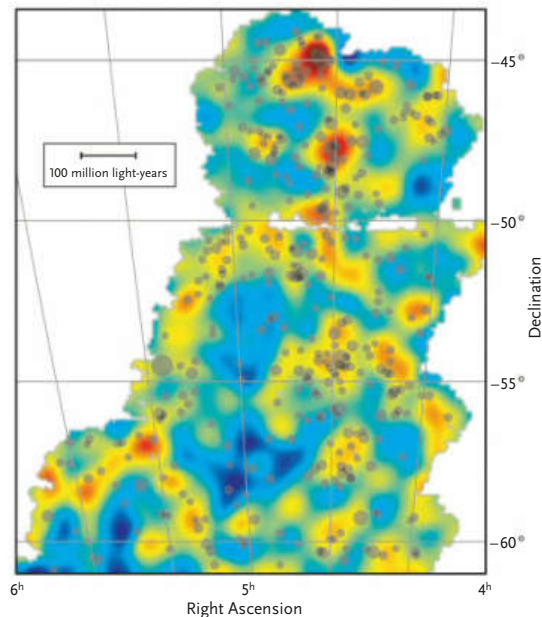
Using the observed smearing, Vikram's team constructed a 2D dark matter map (shown at right) and plotted out how much dark matter lies along lines of sight within a 139-square-degree subset of the area. Generally, the observations support the picture of the universe as a cosmic spider web, with galaxy clusters strung along nodes and filaments of

dark matter like so many caught flies. But clusters don't exactly trace the underlying dark matter distribution, because normal matter and dark matter follow different physical laws.

Working on a much smaller scale, Mathew Madhavacheril (Stony Brook University) and colleagues conducted a different study using the Atacama Cosmology Telescope to measure dark matter's smearing effect, not on the light from faraway galaxies, but on the most well-travelled light in the universe: the cosmic microwave background (CMB).

The team looked for sharp brightness changes in the CMB on arcminute scales, corresponding in this case to the few million light-years that an individual galaxy's dark matter halo spans. The astronomers found about 12,000 blips that matched up with galaxies listed in a Sloan Digital Sky Survey catalogue. Each of these galaxies has a massive halo roughly 10 times that of the Milky Way.

Simply measuring the signal from individual galaxies' dark matter halos is an accomplishment — little has been done on these small scales before. The average dark halo's mass



By measuring dark matter's smearing effect on galaxy shapes, the Dark Energy Survey mapped out the mysterious stuff's density over a large swath of sky. The colour scale reflects dark matter density (red high, blue low); grey circles mark galaxy clusters — bigger circles represent larger clusters.

and concentration, as measured from the blobby composite image the team created, so far match what's expected from dark matter simulations. Researchers will apply the same technique to data obtained from the Advanced ACT polarisation survey taking place between 2016 and 2018, which will cover 10 times the sky area. Eventually, Madhavacheril hopes to trace the growth of dark matter halos over cosmic time.

■ MONICA YOUNG

LUNAR Moon's mysterious twilight clouds from comets

Using measurements from NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft, Mihály Horányi (University of Colorado, Boulder) and colleagues have revealed the distribution, origin and size of clouds of dust particles that float above the Moon's surface at dawn and dusk.

These dust clouds were discovered in 1968, when NASA's last robotic lunar lander, Surveyor 7, took images of a strange twilight glow along the lunar horizon. The glow comes from light scattering off fine dust particles.

LADEE's measurements reveal that the dust cloud is much closer to the Moon's

surface and less dense than previously thought. They also confirmed the dust's origin: comets. LADEE recorded an asymmetric dust cloud instead of a circular one along the Moon's day-night line. If the dust is coming from asteroids, as was originally thought, then the resulting impacts would produce a much weaker and more symmetric cloud, due to the particles' near-circular orbits as they move inward toward the Sun. In addition, the team also found that the cloud increases in density during annual meteor showers, which generally come from comet debris, the team reports in the journal *Nature*.

These observations rekindle the debate

about what causes the dust to levitate and hang about the terminator line in the first place. The most generally accepted theory, *static levitation*, points to changes in charge: shaded areas become negatively charged when the solar wind bombards the surface with electrons, whereas sunlit areas become positively charged by the Sun's photons displacing these electrons. Once an area becomes charged, the dust particles begin to leap about, attempting to get away from their like-charged neighbours. The Moon's terminator would thus be whipped into a chaotic frenzy.

■ ANNE MCGOVERN



Rosetta spots sinkholes on its comet

The spacecraft orbiting Comet 67P/Churyumov-Gerasimenko has found 18 holes in the nucleus. (And no, mission planners didn't think to pack golf clubs.)

ESA's Rosetta spacecraft has been orbiting Comet 67P since August 2014, gathering observations of the funny-looking nucleus, which is shaped rather like a dog's head. The observing campaign has turned up the new 18 pits. They're not the first holes seen on comet nuclei, but they are the first that look like this. The pits tend to cluster together in small groups, and they range from 50 to 310 metres wide. Some pits are cylindrical and deep; others are shallow. The deep ones seem to be 'active,' with dusty jets spewing from their walls or floors. The deepest one reaches more than 200 metres below the surface.

The holes can't be from erosion, because erosion wouldn't create such nicely circular holes. And outbursts from the nucleus exhume only a thousandth as much material as a typical large, active pit would have expelled.

Instead, Jean-Baptiste Vincent (Max Planck Institute for Solar System Research, Germany) and colleagues think the pits are sinkholes. Somehow, the team writes in the journal *Nature*, cavities form beneath the comet's surface. Once the cavity's ceiling becomes too thin to support its own weight, it will collapse, creating deep, circular pits like those observed. The collapse would expose fresh material in the pit's sides, which would then partially sublimate away and fill the pit with debris. That would explain both why deep, cylindrical pits seem to be active and why quiescent pits have had their sides eaten away and their bottoms filled with rubble. But why the cavities form remains unclear.

■ CAMILLE M. CARLISLE

MISSIONS Philae phones home

After seven months of electronic hibernation, Philae awakened on the surface of Comet 67P/Churyumov-Gerasimenko in mid-June and resumed contact with its handlers on Earth.

When last heard from, early on November 15, 2014, the European Space Agency's washing-machine-size lander had survived an unexpectedly rough-and-tumble arrival on the comet's surface. Its transmissions ended prematurely, after only 57 hours, because Philae had wedged itself in a heavily shadowed location that offered little direct sunlight to recharge its onboard batteries.

But the comet's changing solar geometry eventually provided much more sunlight, enough to revive Philae's basic functions. About 85 seconds of telemetry, relayed via the lander's comet-orbiting mother ship, Rosetta, reached Earth on June 13th at 20:28 Universal Time. Then the lander inexplicably went silent again, despite multiple attempts to restore contact,

until a 22-minute-long communication session on July 9th. This second contact confirmed that Philae is receiving commands, one of which was to transmit measurements from its radar sounder.

Philae appears to be in good shape despite its extended shutdown. More than 8,000 packets of data are stored in the craft's mass memory, which, when finally relayed to Earth, should reveal details about the comet's activity during the few days prior to when the lander last phoned home. Philae can only transmit these data when Rosetta is within its line of sight.

The mission team also hopes the renewed transmissions will help them triangulate the landing site's exact location, which remains unknown. More importantly, Philae woke up in time to perhaps add important ground-zero measurements of the nucleus' activity surge as Comet 67P neared perihelion on August 10th.

■ J. KELLY BEATTY

BLACK HOLES

Too big for its britches

The supermassive black hole CID-947 is at least 10 times too massive for its host galaxy, raising questions about how closely galaxies and black holes actually coevolve.

On average, a supermassive black hole has a mass 1/100 to 1/1000 that of its host galaxy. This consistent relationship has led astronomers to suspect that a black hole's growth and that of its host galaxy are intertwined.

But shining at us from a mere 2 billion years after the Big Bang, CID-947 has 1/8 its galaxy's mass. To look like black hole-galaxy systems we see today, the galaxy would have to grow by maybe another factor of 10, without the black hole growing at all, Benny Trakhtenbrot (ETH Zurich, Switzerland) and colleagues report in the journal *Science*. If so, that would suggest that black holes and galaxies don't grow in lockstep; instead, black holes evolve quickly and their host galaxies follow. Other observations have also hinted at this independent evolution, but uncertainties in all the results make it difficult to know for sure. Read the behind-the-scenes discovery story at <http://is.gd/cid947>.

■ SHANNON HALL

GALAXIES

Dark galaxies suffuse Coma

Late last year, astronomers reported a weird find: 47 'dark' galaxies mingling with the other denizens of the Coma Cluster. Now another team has discovered a whopping 854 more of these faint, fluffy and hard-to-explain objects in the same cluster.

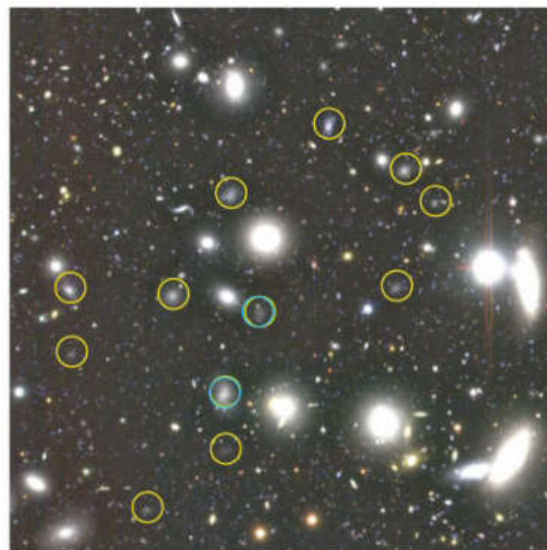
Even ordinary galaxies contain a lot of dark matter, which makes up about 83% of the universe's mass. But the dark galaxies discovered within the Coma Cluster contain even more of the exotic and invisible stuff, up to 98% of their total mass.

The galaxies are incredibly dim, making them difficult to pick out even with advanced instruments. Yet despite their lack of stars, most still

span roughly the size of the Milky Way. Only dark matter could hold this diffuse collection of stars together in the collision-prone environment of a crowded galaxy cluster.

Jin Koda (Stony Brook University) and colleagues found the dark galaxies by poring over archival images from the 8.2-metre Subaru Telescope. Astronomers haven't seen so many of these objects elsewhere, suggesting that the crowded cluster environment strips star-forming gas out of these galaxies, leaving only dark matter behind, the team reports in the *Astrophysical Journal Letters*.

■ J. KELLY BEATTY



This colour composite of Subaru images shows some of the newly discovered 'dark' galaxies, circled in yellow. Blue circles highlight two galaxies discovered late last year. The image above covers less than 1% of the studied area. NAOJ

Mystery of dust-poor early galaxies

New submillimetre wavelength observations reveal low levels of dust in nine early galaxies. The result is in line with previous predictions, but it does highlight a problem with some observers' calculations.

Peter Capak (Caltech) and colleagues used the ALMA array, with other optical and infrared data, to look at nine galaxies shining at us from about a billion years after the Big Bang. The astronomers detected dust emission from only four of the nine galaxies, but detected a form of ionised carbon known as [CII] in all nine.

As the authors explain in the journal *Nature*, the presence of all this ionised carbon suggests a low level of dust. Carbon likes linking up with other elements to form molecules, so it doesn't hang around by itself for long. But with few heavy elements to bond with, and with minimal dust around to protect the carbon atoms from the ionising influence of ultraviolet radiation — which is pouring out from the young stars in these nascent galaxies — the normally rare [CII] has become fairly concentrated.

The implication is that these galaxies have amounts of dust similar to that in the Small Magellanic Cloud (SMC). That's unsurprising: dwarf galaxies likely undergo star formation in on-and-off fits,

so they'll take longer to build up dust.

Interestingly, two of the team's galaxies have similar amounts of dust to A1689-zD1, the remarkably dusty galaxy that raised eyebrows earlier this year. But A1689-zD1 existed 300 million years before these galaxies. What counts for a 'moderate' amount of dust a billion years after the Big Bang is 'challenging' only 700 million years after the Big Bang, says Veronique Buat (Astrophysics Laboratory of Marseille, France). Perhaps in general dust buildup was slow, but some galaxies jumped the gun and got dusty fast.

Dust warmed by starlight is usually the dominant source of a galaxy's infrared emission, a fact astronomers exploit to estimate the rate of starbirth in distant galaxies. If there's less dust in early galaxies, then the particular correlation used to calculate the starbirth rate in an individual galaxy will give an estimated rate that's too high. But the assumption probably has much less of an effect on estimates of star formation across cosmic time, because most stars form in less luminous galaxies that we already assume have very little dust. And studies that assume a galaxy's dust properties are similar to the SMC's appear okay as well.

■ CAMILLE M. CARLISLE

EXOPLANETS

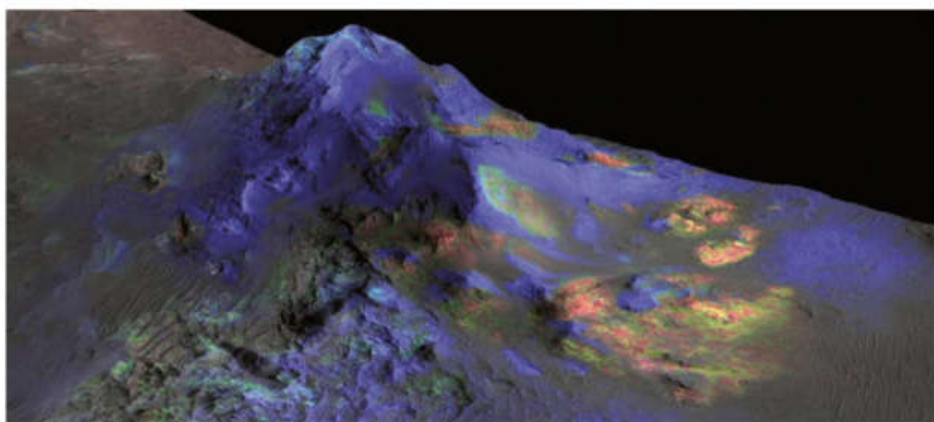
Planet with a tail

Astronomers have confirmed that the exoplanet Gliese 436b is trailing a gigantic, coma-like cloud behind itself in its orbit. Gliese 436b has about the mass and size of Neptune but orbits its red dwarf star in just 2.6 days. In 2014, astronomers watched Gliese 436b pass in front of its host star in ultraviolet (UV) light and found that the star stayed dim long after the planet had ostensibly finished transiting.

David Ehrenreich (Geneva Observatory, Switzerland) and colleagues have now confirmed that observation. The team studied the planet's transit in a specific UV spectral line called Lyman alpha, which is associated with hydrogen. The astronomers thus found that the planet blocks more than 50% of the host star's UV light, whereas it blocks less than 1% of its visible light. The result suggests that the planet is trailing a gigantic, comet-like tail of hydrogen behind itself that continues to block starlight after the main transit, the team writes in the journal *Nature*. Read more and watch a video of the system at <http://is.gd/436btail>.

■ JOHN BOCHANSKI

MARS The glint of Martian glass



Scientists have found deposits of impact glass (green) preserved in several Martian craters, including Alga (crater's central peak shown above). Also detected are the minerals pyroxene (purple) and olivine (red). The colour-coded composition information from NASA's Mars Reconnaissance Orbiter is shown over a terrain model based on observations, but with the vertical dimension exaggerated by a factor of two. NASA / JPL-CALTECH / JHUAPL / UNIVERSITY OF ARIZONA

Scientists have detected glass in several Martian craters, created by the fierce heat of impacts that melted these parts of the Red Planet's surface.

Mars is pockmarked with craters, but thus far planetary scientists haven't definitively found impact glass there. They have seen glass in general, though: a huge deposit lies in the north polar sand sea and across the northern plains, covering some 10 million square kilometers. But that glass likely came from ancient, explosive volcanism.

Kevin Cannon and John Mustard (both at Brown University) combined lab work and spacecraft observations

to find the newly identified impact glass. Researchers can differentiate between glass and minerals based on how the material absorbs certain wavelengths of light. So Cannon whipped up a rock-powder recipe similar to Martian dirt, then fired it to create glass. With the pseudo-Martian glass in hand, he determined the material's spectral pattern.

Then the team looked for this signal in several impact craters observed by NASA's Mars Reconnaissance Orbiter. Their homemade computer algorithm successfully teased glass's signature out of the spectroscopic mess of many of the craters. The glass also matches

up well with other features interpreted as impact-spurred, sometimes even following the sharp margins of melts (such as in Alga Crater) or staying confined to a melt's thin draping across the surface (as in Ritchey Crater), the team reports in the journal *Geology*.

"This is pretty cool," says Briony Horgan (Purdue University), who co-discovered the northern glass deposit. Detecting glass's spectral signal is a major challenge: glass is partially translucent, so it doesn't absorb light well. On the other hand, iron-bearing minerals like olivine and pyroxene — which also appear in the craters — absorb a lot more light, producing absorption bands that are much deeper and easier to recognise. "Because they absorb so much more light than glass, their signature tends to swamp out the glass signature," she says.

Glass is an intriguing find because, since it forms by very rapid cooling, it's good at entombing biosignatures, Cannon explains. "If the impact melt cooled slowly, it would cook any kind of organic matter trapped inside," he says. Plus, glass is friendlier to microbes, with weaker chemical bonds than rock, making it easier for microbes to tunnel inside.

Less exotically, scientists could use this type of spectral analysis to find many other kinds of minerals on Mars, or on other bodies, and to better understand the range of materials impacts produce.

■ CAMILLE M. CARLISLE

IN BRIEF

Exoplanet or Illusion? An analysis of stellar activity casts doubt on whether Kapteyn b, a supposed super-Earth circling in its star's habitable zone, is real. Kapteyn b is one of two exoplanet candidates circling Kapteyn's star, an old, cool red dwarf. Astronomers detected it using the radial velocity method, which looks at the small blue- and redshifts in starlight created as the star and planet move around their common centre of mass. But starspots and other activity can mimic this effect. Paul Robertson (Penn State) and colleagues found Kapteyn b's orbit is "worryingly close" to a particular fraction of the star's rotation period. They conclude

in the *Astrophysical Journal Letters* that the exoplanet isn't real. But other astronomers are unconvinced, and the planet's existence remains disputed.

■ EMILY POORE

Hot Jupiter Stratospheres Explained?

When present in an atmosphere, radiation-absorbing molecules create an inversion layer, with the temperature first decreasing, then increasing, with altitude. This happens because certain molecules at the top of the atmosphere absorb radiation, keeping the middle parts cool. In the Solar System,

compounds like ozone and methane do the job, but they are too flimsy to withstand the heat in a hot Jupiter's stratosphere. Using the Hubble Space Telescope, Corey Haynes (NASA Goddard) and colleagues found tantalising traces of the heavy-duty absorber titanium oxide on the hot Jupiter WASP-33b, as reported in the *Astrophysical Journal*. Astronomers had hoped this molecule could explain the inversions seen on hot Jupiter planets, but until now no one had detected it. If confirmed, this detection would be the first definitive correlation. ♦

■ ANNE MCGOVERN



Jodrell Bank and the VLA

Two famous radio astronomy facilities unveiled a hidden cosmos



Some of the 27 dishes of the Karl Jansky Very Large Array radio telescope facility.
W.GRAMMER/NRAO/AUI/NSF

Nothing boosts the pace of scientific discovery more than a new way of collecting and analysing information. This is particularly true in astronomy. We have would have learned very little about the universe with only our unaided eyes to rely upon.

So it is appropriate to note that the month of October marks the anniversaries of the inauguration of two iconic radio telescopes, instruments which have played a major role in the growth of the study of the universe through the radio waves that objects in it emit. Since humans are not naturally sensitive to such radio waves, we had no idea they existed until the appropriate means of detection were developed.

October 1957 marked the first operation of what was at the time the largest radio telescope in the world, a dish more than 75 metres in diameter; it is still the third-largest steerable dish nearly 60 years later. The instrument was built at Jodrell bank in the UK, associated with the University of Manchester and with the pioneering work of Sir Bernard Lovell. He had worked on the development of radar during WWII, where chance discoveries, and major advances in radio technology, gave great stimulus to the embryonic science of radio astronomy. The facility,

once known prosaically as Mark One, is now called the Bernard Lovell Observatory.

Hardly any kind of object in the cosmos has escaped the attention of the Jodrell Bank radio 'eye': meteors, the Moon, the Milky Way, the Andromeda Galaxy and so on. Used as a giant radar set, it measured the distance to the Moon and to Venus. Significant discoveries include the first millisecond pulsars (neutron stars which rotate thousand times a second), and the first 'gravitational lenses' predicted by Einstein. Jodrell bank also joined the SETI enterprise, looking for signals that might come from extra-terrestrial civilisations.

Jodrell Bank also played an important role in communicating with satellites in orbit around the Earth and space probes beyond (though this well-publicised activity occupied only a small fraction of the telescope's time). Indeed the first operation of the telescope was just in time to follow the launch of Sputnik One, the first artificial satellite. Later it tracked the Russian unmanned moon probe Luna 9, and was able to intercept its transmissions of photographs of the lunar surface. These were published in the British press before the Russians could release them.

Nearly a quarter of a century later,

another iconic radio telescope gathered 'first light'. By that time it was realised that building larger dishes of the Jodrell Bank type was doomed to failure. The engineering difficulties were just too great. The alternative approach was dubbed 'aperture synthesis', spreading a number of small dishes over a large area and connecting them together in such a way that they behaved like a single large dish, at least in terms of the degree of detail they could observe.

That was the principle behind the Very Large Array (VLA), commissioned in the desert of New Mexico in October 1980. The VLA had 27 fully steerable dishes each about 30 metres in diameter, arranged in a Y-shaped pattern, with many of the dishes running on railway tracks so that the distances between them could be changed. In this way it was possible to 'synthesise' the equivalent of a single radio telescope 36 kilometres across. That gave it the 'resolving power' (ability to see fine detail) equivalent to the best optical telescopes.

As with its predecessor at Jodrell bank, the highly versatile VLA turned its attention to a very broad range of astronomical tasks, such as mapping the distribution of hydrogen throughout Milky Way. It also received radio transmissions from the Voyager 2 spacecraft as it passed by Neptune.

After three decades of operation, the VLA underwent a major upgrade, particularly of its electronics, which improved some of its capabilities by factors of 1,000 or more. It seemed appropriate to mark this 'rebirth' by giving the instrument a new name, as had been done at Jodrell bank. After canvassing public and private opinion, the authorities decided to call it the Karl Jansky Very Large Array, after the Bell Telephone company engineer whose serendipitous discoveries in the 1930s of radio waves from the Milky Way formed the starting point for radio astronomy. As with all pioneers, he would have been astounded with how far those first discoveries had led and the scale and power of the instruments now employed. ♦

David Ellyard presented SkyWatch on ABC TV in the 1980s. His *StarWatch StarWheel* has sold over 100,000 copies.



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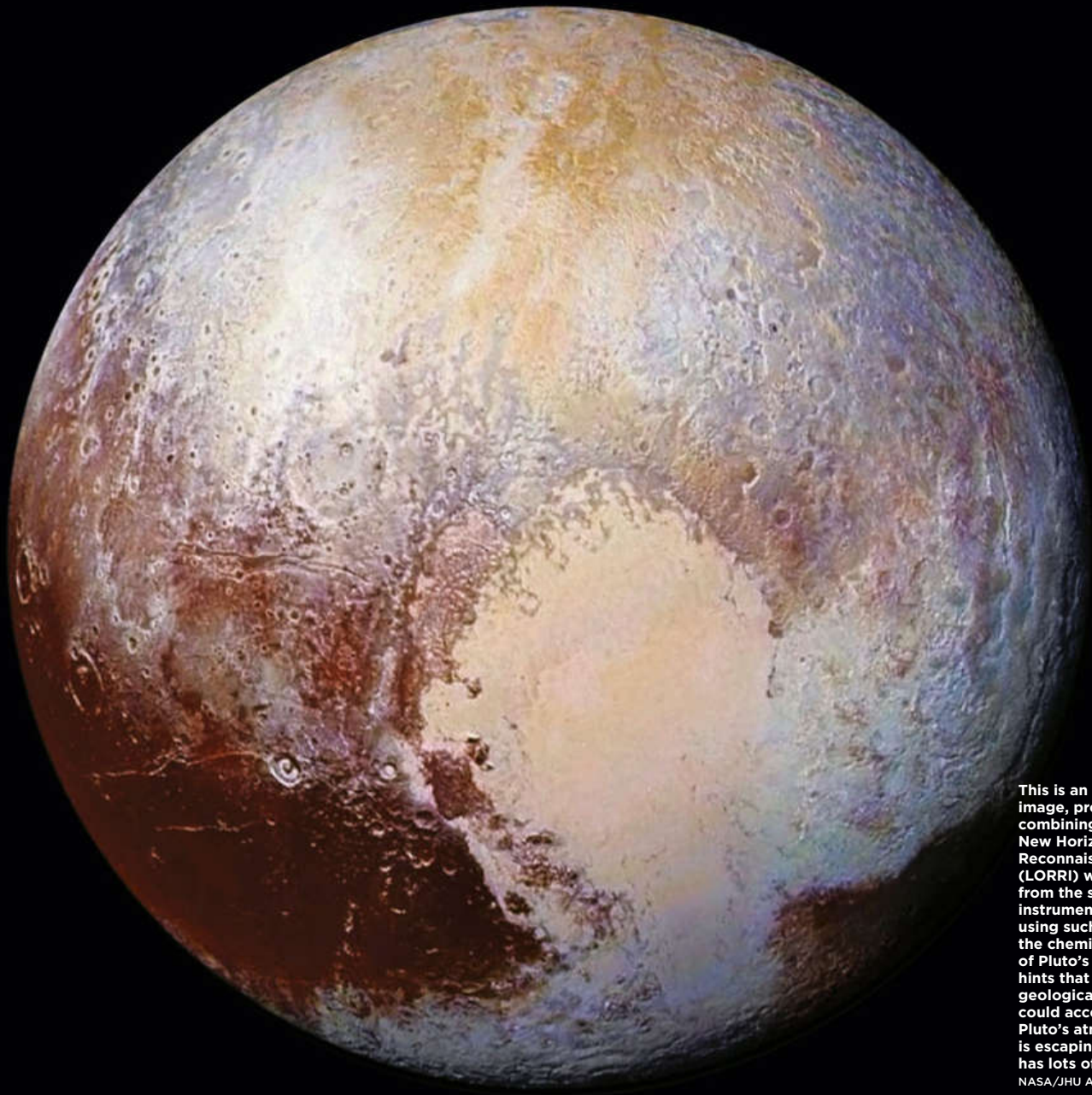
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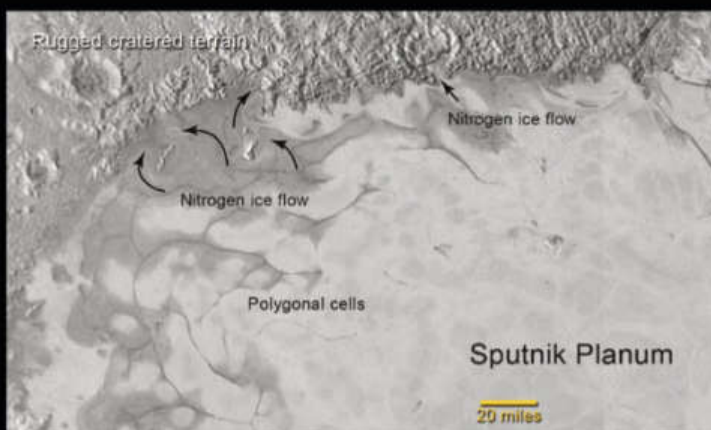
**More images from New
Horizon's historic fly-by**



After New Horizons had zipped past Pluto, it spun around, looked back and took images of the dwarf planet's atmosphere backlit by sunlight.
NASA/JHU APL/SwRI

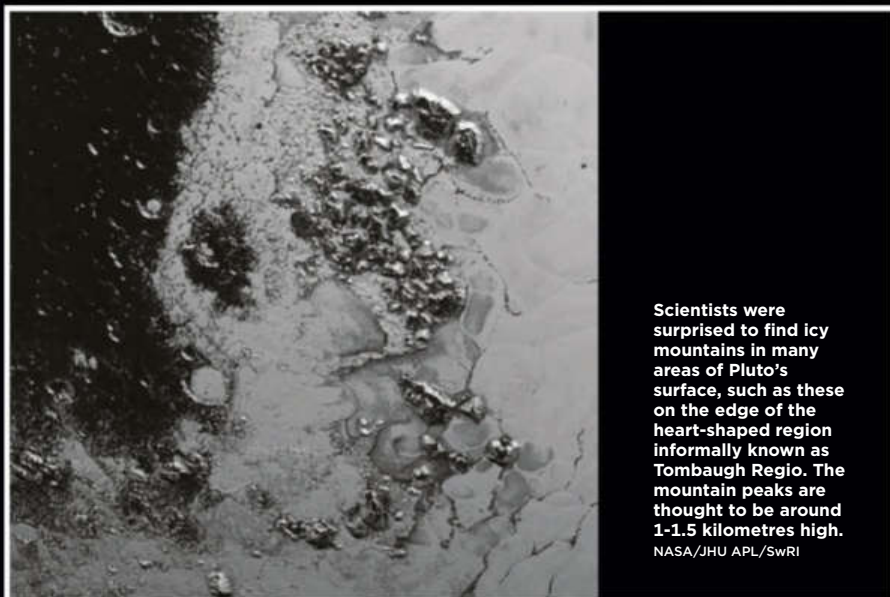


This is an enhanced-colour image, produced by combining images from New Horizons' Long Range Reconnaissance Imager (LORRI) with colour data from the spacecraft's Ralph instrument. Scientists are using such images to study the chemical composition of Pluto's surface. There are hints that Pluto may still be geologically active, which could account for why Pluto's atmosphere (which is escaping into space) still has lots of nitrogen. NASA/JHU APL/SwRI



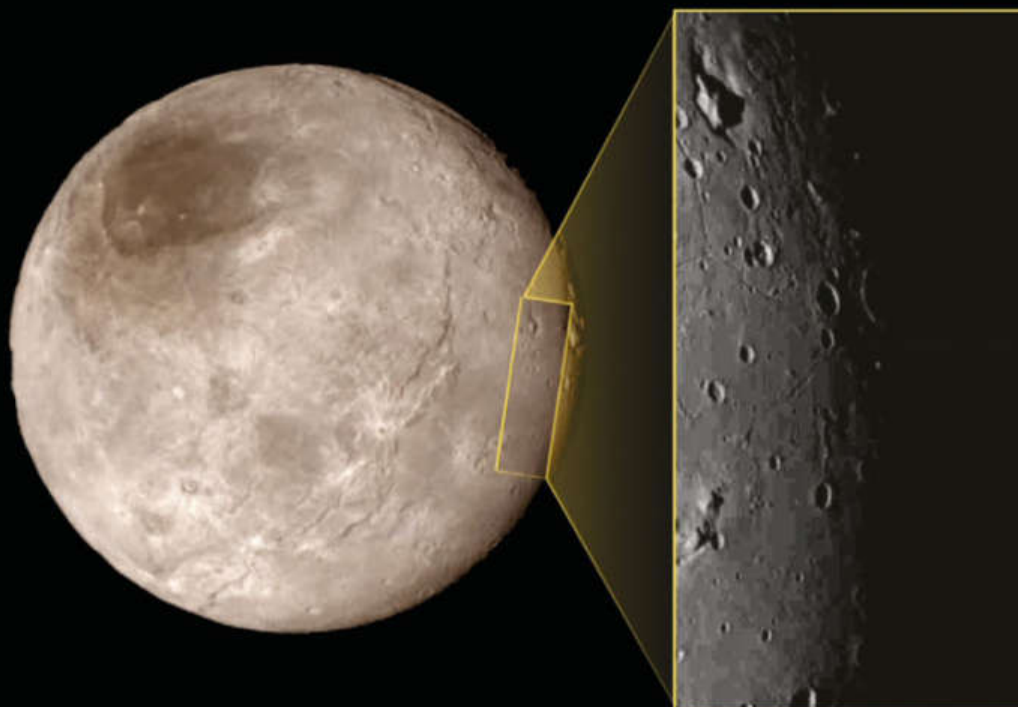
The region informally named Sputnik Planum features swirling patterns that are indicative of flowing ices, similar to glaciers on Earth, and other sections characterised by troughs. NASA/JHU APL/SwRI

Pluto encounter



Maybe it's just because it's all new to us, but Charon certainly seems to be one of the most intriguing moons in the Solar System, with craters, ridges, plains and troughs or valleys. The inset shows a depression with a peak inside (top left). Images with much higher resolution are currently stored aboard New Horizons for later relay back to use here on Earth.

NASA/JHU APL/SwRI



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Chaos at Kitt Peak

As science agencies tighten their belts, some publicly funded telescopes are seeking inventive paths forward.

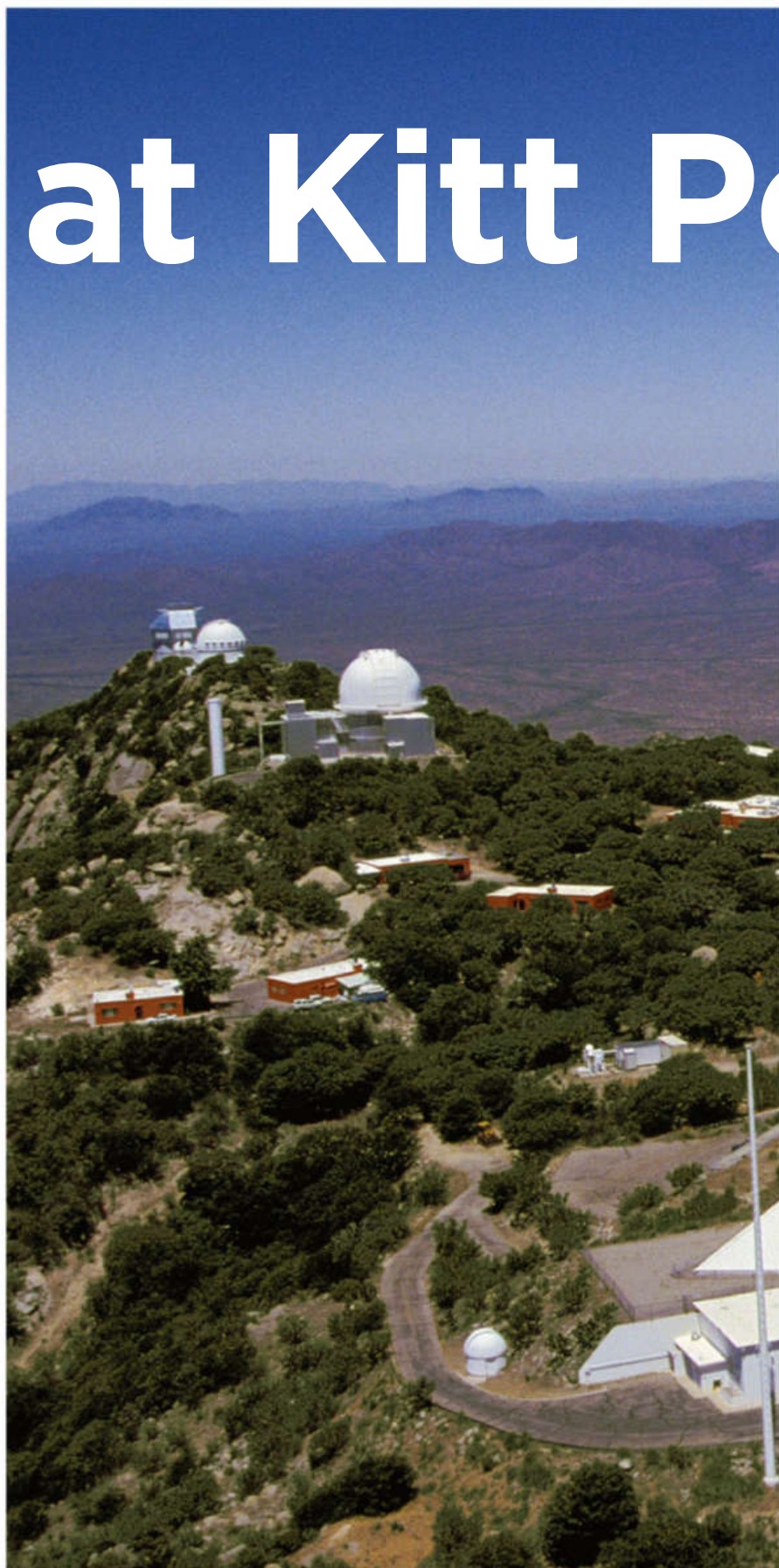
Although the future of the 2.1-metre telescope atop Kitt Peak in Arizona seemed quite dismal at the time, on May 22, 2014, I joined two ‘retired’ professionals-turned-amateurs, Mark Trueblood and Larry Lebofsky, for a night of observations there. Their goal was to capture new images of some potentially hazardous asteroids — having orbits that might slam them into Earth — so that dynamicists could better calculate those orbits.

At first their effort was stymied by clouds — what Lebofsky called “big, puffy, white things.” So we hung out, waiting, and chatted about the state of observational astronomy and the impending loss of the 2.1-metre. A workhorse for decades, it was scheduled for shutdown in two months because of funding shortages. The instrument was one of only a handful of professional telescopes in the USA available to the general astronomy community and to highly skilled amateurs like Trueblood and Lebofsky. It was for this reason that both were willing to wait as long as necessary for the clouds to clear. As Trueblood noted that night, “I really want to get some data this last time.”

The threatened shuttering of the 2.1-metre, however, was part of a much larger financial crisis for four scopes on Kitt Peak. With the US National Science Foundation (NSF) faced with a flat budget, as well as increased costs to build and operate several new state-of-the-art telescopes, something had to give. And as explained by David Silva, director of the National Optical Astronomy Observatory (NOAO), when the NSF asked the astronomical community to list its scientific priorities using existing facilities, “unfortunately Kitt Peak came up on the short end.”

Nor was the NSF alone in putting its NOAO and National Solar Observatory (NSO) Kitt Peak scopes at the bottom of

TELESCOPE MOUNTAIN Two dozen telescopes sit on or near Kitt Peak’s summit. The unusual triangle of the McMath-Pierce Solar Telescope (foreground) was designed to mimic the shape of a sundial’s gnomon. The diagonal tube extends deeper underground than it does into the sky. NOAO / AURA / NSF



Peak



ROBERT
ZIMMERMAN





THE MAYALL The 4-metre Mayall is the largest optical/infrared telescope on Kitt Peak. Built in the 1970s, it's sturdy enough to handle the planned Dark Energy Spectroscopic Instrument, which astronomers will use to conduct a 5-year survey documenting the universe's expansion over time. PETE MARENFELD / NOAO / AURA / NSF

the list. During this same time period Yale University also decided to withdraw from the mountain.

As a result, in 2014 Kitt Peak was threatened with some major changes and cutbacks, with several of its two dozen telescopes on the financial chopping block.

"The astronomical community is facing a situation where the majority of astronomers who don't reside or work at institutions that own their own telescopes are just going to be out of luck," says John Salzer (Indiana University), president of the 3.5-metre WIYN telescope's board of directors. "They are not going to have access to ground-based telescopes."

Building a city of telescopes

Kitt Peak's astronomical history began in the 1950s. At that time a panel of astronomers recommended that the NSF establish a national observatory for astronomical and solar research as well as for education. Such a facility would provide American astronomers access to professional-grade telescopes, even if their respective universities had no

// The majority of astronomers who don't reside or work at institutions that own their own telescopes are just going to be out of luck. //

money to build or maintain such instruments themselves.

Based on this recommendation and after several years of site research, Kitt Peak was chosen as the best location for the national observatory. The NSF signed a lease in 1958 with the Tohono O'odham nation for the use of about 110 hectares on top of the mountain and then created cooperative agreements with what would later become NOAO and NSO for operating various telescope facilities on the summit.

During the next half century, Kitt Peak attracted telescopes of all shapes

and sizes, capable of observing in optical, infrared and radio wavelengths. Some, like the 4-metre Nicholas U. Mayall Telescope and the McMath-Pierce Solar Telescope, were national observatories planned and constructed for the mountain itself. When completed, the Mayall was the second-largest telescope in the world, while the McMath-Pierce still remains tied for world's largest solar telescope.

Other telescopes originally housed at different locations moved to Kitt Peak to take advantage of its dark skies and clear air. Case Western Reserve University's 0.6-metre telescope, for example, was built in 1939 in Cleveland but was relocated to Kitt Peak in 1979.

The ownership and operation of these telescopes also varied. Although NSF leases Kitt Peak from the Tohono O'odham nation, it does not actually own or operate most of the two dozen telescopes there. Instead, NOAO, under its agreement with NSF, acts as the landlord — maintaining the roads and providing the utilities — while numerous other universities, partnerships, and organisations (such as NSO) do the owning and operating.

For example, the WIYN 3.5-metre was built in the 1990s and operated by a partnership of three universities — the University of Wisconsin, Indiana University and Yale — plus NOAO, with the four holding a 26%, 17%, 17%, and 40% share of the partnership, respectively.

Similarly, NSO controlled and operated the two solar scopes on the mountain, the McMath-Pierce Solar Telescope and (until 2014) the Synoptic Optical Long-term Investigations of the Sun (SOLIS) facility, with NOAO again acting as landlord. NSF funds both NOAO and NSO, making the relationship even more convoluted.

Thus, despite being proprietor over this telescopic metropolis, NOAO fully owns only two telescopes there, the 4-metre Mayall and the 2.1-metre. For decades, both of these, as well as NOAO's 40% of WIYN time, were made available for serious research to anyone in the general astronomy community,

including observers such as Trueblood and Lebofsky.

Budget squeeze

In 2014, however, this decades-long arrangement faced some major changes, including the threatened (temporary) slowdown of the Mayall and the shutdown of three telescopes: the 2.1-metre, the McMath-Pierce Solar Telescope and WIYN.

The changes first began with NSO, which in 2003 decided that it needed to withdraw from Kitt Peak. This decision was part of NSO's long-term plan, which recognised that for it to operate the new 4-metre Daniel K. Inouye Solar Telescope (DKIST) in Hawai'i (slated for first light in 2019), the agency needed to find additional operating funds. Those funds were to come from the money used to operate facilities at Kitt Peak.

NSO therefore decided to remove SOLIS to an as-yet-undetermined new

location, while handing off the operation of the McMath-Pierce Solar Telescope to someone else or closing it down entirely. Originally the plan called for a slow ramp-down of operations and funding, to be completed in 2019, so that there would be time to find another entity to take over McMath-Pierce.

In 2012, however, a NSF review by a committee of astronomers mandated that this ramp-down be accelerated and that NSO be off the mountain no later than the end of 2015. As a result "there will be a little bit of a gap," explains NSO Deputy Director Mark Giampapa. "We are working hard to find potential partners who could operate the telescope facilities during and after this ramp-down period."

As part of this effort NSO has solicited the solar science community. They have so far assembled a tentative consortium of about eight scientists from both NASA and various universities who "are in the process of



THE WIYN The 3.5-metre WIYN telescope, named for its original partners (University of Wisconsin, Indiana University, Yale and NOAO), sits at the southern end of Kitt Peak. NOAO's portion of observing time will now be dedicated to exoplanet studies.

MARK HANNA / NOAO / AURA / NSF

seeking funds” for the telescope’s continued operation, he says. So far, however, this effort will only keep the telescope operating through 2015.

Beyond that date the future remains unknown. NSO is even looking into what it would cost to decommission McMath-Pierce. This decommissioning could range from “mothballing to total site deconstruction and reclamation,” Giampapa says.

Crises and comebacks

That same 2012 NSF review also accelerated NOAO’s exit from Kitt Peak and the divestment of its telescopes there. The NSF reduced funds for the Kitt Peak optical telescopes to pay for operations elsewhere, chiefly the Atacama Large Millimetre/submillimetre Array in Chile and NSO’s DKIST, explains Robert Blum, NOAO’s deputy director. Eventually these savings will also help pay for the Large Synoptic Survey Telescope when it begins operations in the next decade.

The review also decided, however, that NOAO would remain as Kitt Peak’s landlord, maintaining the utilities and roads as it has for decades.

The 4-metre Mayall fortunately had a new collaboration under way. Based on the 2014 recommendations of a panel of physicists, the US Department of Energy’s Lawrence Berkeley National Laboratory will use it to undertake a 5-year survey to study dark energy. The project will use the Dark Energy Spectroscopic Instrument, to be installed sometime in the 2018–19 timeframe. NOAO will continue to operate the telescope, but the Department of Energy will fund it.

As with NSO, NOAO’s plan had been to ramp down its budget slowly until then, to maximise use of the telescope during this transition. The NSF review mandated, however, that NOAO also divest itself from Kitt Peak by the end of 2015. As a result, the use and availability of the 4-metre during the transition period will be greatly curtailed. “We will have to do some things like take some instruments out of rotation, provide fewer instruments on the telescope, and most likely go to longer, survey-type programs,” explains Lori Allen, director of Kitt Peak National Observatory.

Throughout 2014 and into the beginning of 2015 the 2.1-metre telescope remained completely orphaned, however. Kitt Peak issued a



CLOUDY SKIES FOR SOLAR TELESCOPE
The McMath-Pierce Solar Telescope ties with Big Bear Observatory for world’s largest solar telescope, with an aperture of 1.6 metres. This interior shot looks up the instrument’s tunnel (the telescope has a focal length of 87 metres). The telescope’s financial future remains unclear.

PETE MARENFIELD / NOAO / AURA / NSF

call for proposals from the community, for anyone who wanted to operate the 2.1-metre. By mid-2014 it had received four proposals with serious inquiries from a total of six parties, but none could be finalised before 2015.

Thus, on July 31, 2014, the 2.1-metre was officially shut down.

In March 2015, however, a university partnership won the right to take over the telescope. The agreement was not yet public when this article went to press, but if all goes well, Allen hopes the telescope will reopen for research sometime this year.

Then there are the budget problems at the 3.5-metre WIYN telescope. In 2013 Yale decided that its research and academic priorities no longer included WIYN, and it formally pulled out of the partnership in 2014. This pullout, combined with NOAO’s decision to cease its participation, left WIYN with a loss of 57% of its financial support.

Since then the remaining partners have been scrambling to find others to pick up the shortfall, with mixed success. In late 2014 they obtained one new partner, the University of Missouri, but as Salzer noted then, “We are not at the point of having filled our dance card. We are substantially short of that.”

Early in 2015, however, NASA stepped forward and proposed that, in partnership with the NSF, it assume the NOAO portion of WIYN’s partnership. The deal will have NASA build and install on WIYN an extremely precise radial-velocity spectrometer, designed to observe candidate exoplanets and confirm their existence while also

obtaining their masses. NOAO will manage this program for the agencies and so will remain a WIYN partner. Its share of telescope time will still be open to the community, but with priority given to proposals devoted to this work.

In early 2015 NASA put out a call for proposals to build this instrument. In the meantime WIYN remains fully open and funded, available for exoplanet as well as general research.

The future

Of the four Kitt Peak observatories faced with a budget crunch, only one, the McMath-Pierce Solar Telescope, currently faces shutdown. There is a strong effort to prevent that shutdown or make it very temporary.

Despite Kitt Peak’s improved situation, my evening with Trueblood and Lebofsky at the 2.1-metre remains bittersweet. While the telescope might be saved, it wasn’t going to be saved for them. Under the telescope’s new partnership, serious, independent researchers will only have access to 20 nights per year; the other nights now belong to those paying for its operation.

And although the larger national observatory instruments in the works will also be open to all, competition will be stiffer on these big-aperture scopes, and there will be fewer nights available. The question of where independent astronomers will go in the future for telescope time remains unanswered. ♦

Robert Zimmerman posts regularly on his website, behindtheblack.com, on science, technology, politics and culture.

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Lick Observatory's



TRUDY E. BELL

The axe fell on September 16, 2013. A letter to the University of California Observatories stated that, starting no later than fiscal year 2016–17, the UC Office of the President (UCOP) “will implement a glide path of funding for Lick Observatory ending with the elimination of UCOP funding for Lick by FY 18–19 at the latest.”

Sitting atop 1,280-metre Mount Hamilton, east of San Jose, Lick was the world's first permanent mountaintop observatory when transferred to UC control in 1888. It has remained at the forefront of optics and astronomy research ever since. Cutting off funds did not, technically speaking, mean that the university system was closing Lick Observatory and its half dozen active research telescopes. It meant the UC system would no longer manage or pay for it — as if your employer told you, “You can still work here. You just need to find someone else to be your boss and pay your salary.”

Although UC astronomers and other Lick supporters had been battling to save the observatory for several years, the news threw them into higher gear. And after more than a year of their perseverance, on October 29, 2014, UCOP rescinded its requirement that Lick become self-supporting and be managed by an entity other than the University of California Observatories (UCO).

The drama that Lick endured is a complicated, politics-laden tale, and the observatory does not yet stand on financial bedrock. But its experience holds important lessons for supporters of other threatened observatories.

An iconic institution

During the California gold rush, entrepreneur James Lick bought land being sold cheaply by men headed for the state's gold fields. Soon, Lick owned vast tracts of prime real estate in San Francisco, San Jose and elsewhere. Inspired by other philanthropists seeking immortality by establishing major observatories, in the 1870s Lick bequeathed US\$700,000 — equivalent to US\$1.45 billion today — to build “a powerful telescope, superior to and more powerful than any telescope ever yet made . . . and also a suitable observatory.”

When transferred to the 20-year-old University of California (then occupying a single campus at Berkeley), the observatory instantly conferred on the fledgling university the status of a world-class research institution. Lick astronomers have conducted research continuously since its 0.9-metre Clark refractor — then the largest in the world — was dedicated in 1888. In 1892 E. E. Barnard used it to discover Amalthea, the first Jovian moon discovered since Galileo's observations nearly three centuries prior. Lick's 3-metre Shane reflector was

close call

Lick Observatory's funding was cut to zero and then restored. What happened? And what can other endangered observatories learn from the experience?



LIGHTNING STRIKE Long a leader in astronomical research and optics, Lick was temporarily on the University of California's financial chopping block. ALL LICK OBSERVATORY PHOTOS: LAURIE HATCH



the world's second largest when built in 1959, and it's used today for a wide range of astronomical research.

As it grew and evolved, Lick mothballed older instruments and installed new ones. Today the observatory is home to several active research telescopes ranging in aperture from 0.76 to 3 metres, plus a handful of smaller instruments. For nearly two decades its 0.76-metre Katzman Automatic Imaging Telescope has conducted one of the world's most successful searches for extragalactic supernovae. The fully robotic 2.4-metre Automated Planet Finder (APF) began science operations in 2013 and uses precision spectroscopy to detect the tiniest — down to half a metre per second — wobble of stars' positions, created by the gravitational tug of the stars' orbiting planets.

Meanwhile, as UC established other campuses around the state, Lick became the prime teaching and research facility for their astronomy faculty and students. Thanks to Lick, astronomers had access to instrumentation they could not afford to build themselves. Its optical and machine shops also helped develop the twin 10-metre telescopes for the W. M. Keck Observatory atop Mauna Kea and designed the first practical laser guide-star adaptive optics system to 'de-twinkle' stars — first installed on the Shane reflector and now used at many observatories worldwide.

Budget crunch and henhouse fox

Beginning in 1978, however, a series of legislative changes and financial squeezes shrank state support for the UC system. After the 2008–09 economic meltdown, the state slashed UC's budget by a quarter billion or half billion dollars at a go, sometimes twice in a year. Cuts of such magnitude are not readily absorbed even by a complex with an overall budget of some \$20 billion. By 2011, California was spending more on state prisons than on higher education. Overall, state support fell from 78% of the total cost per student in 1990–91 to 39% in 2013–14.

In this context, academic research was under pressure, including UC's astronomy and astrophysics programs, widely regarded as UC's crown jewels. In 2008, UCOP hired former Space Telescope Science Institute director Steven Beckwith as Vice President for

Research and Graduate Studies.

Beckwith's top challenge was to save money as the state cut its intercampus research funding by 40% over the next five years. At the same time, UCO was trying to adequately fund its more expensive collaborations on Keck and the planned Thirty Metre Telescope (TMT), also on Mauna Kea.

But Lick supporters contend that Beckwith's influence was destructive. Letters, articles and reports (many publicly accessible online) document a complex history of deliberations held in closed executive sessions, where he expressed scepticism and half-truths not just about Lick but also about the practicality of adaptive optics and the viability of TMT.

UC astronomers argue that, since Beckwith was the official spokesman and supporter of UC research, his words sowed doubt in the minds of colleagues, funders and others outside the UC system. Astronomers laid out Lick's cost-effectiveness and importance, to no avail. Ultimately, the UCO Board pushed recommendations that led to UCOP's letter instituting a 'glide path' to end Lick funding.

The threats to Lick and the questionable proceedings behind them stirred up criticism in local outlets, plus attention in publications such as *Science* and the *New York Times*. Amateur and professional astronomers and other Lick supporters, led by retired UC astronomer Robert Kibrick, founded Friends of Lick Observatory, dedicated to fundraising and public outreach. Two-thirds of California's congressional representatives petitioned the UC president in a letter spearheaded by congresswoman Zoe Lofgren. The renowned cosmologist Alex Filippenko (UC Berkeley) took a sabbatical semester in 2013 and devoted much time the following year to publicising Lick's plight further and raising funds.

Although verbally and in letters Beckwith and UCOP insisted their intention was not that Lick close, they put no visible support behind fundraising. "Private donors and foundations want to feel they are putting up matching funds — that UC is a fully engaged but cash-strapped contributing partner," explains Kibrick. "Lack of UC support sent a message that UC did not have interest or commitment."

Then events took a fundamental turn. In the summer of 2014, Beckwith left

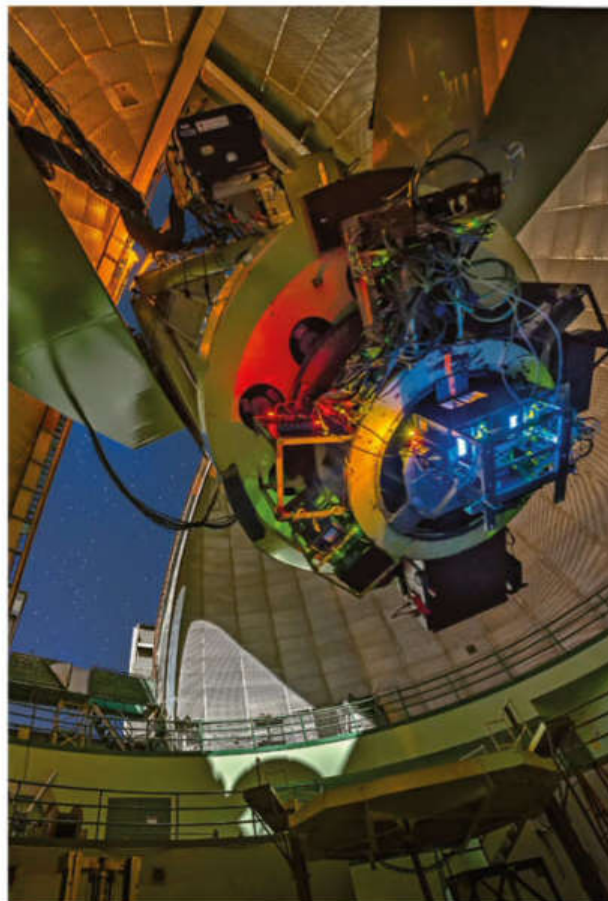
Domes and dollars

The US is not alone in its effort to keep its observatories funded; other countries are also facing tough choices.

In 2012, the UK's Science and Technology Facilities Council announced it was pulling funding from the 3.8-metre United Kingdom Infrared Telescope (UKIRT) and the 15-metre James Clerk Maxwell Telescope (JCMT) on Mauna Kea, so that it could support next-generation mammoth projects such as the Atacama Large Millimetre/submillimetre Array (ALMA).

UKIRT was essentially auctioned off to the University of Hawai'i, University of Arizona and Lockheed Martin, while JCMT went to the University of Hawai'i and the East Asian Core Observatories Association, a partnership of Chinese, Korean and Japanese observatories and institutes.

— Camille M. Carlisle



RESEARCH WORKHORSE The 3-metre Shane telescope is Lick's technology test bed. Astronomers installed on it the first laser guide-star adaptive optics (AO) system in 1995, and today its two spectrographs and state-of-the-art AO make it useful for a range of projects, including large surveys.



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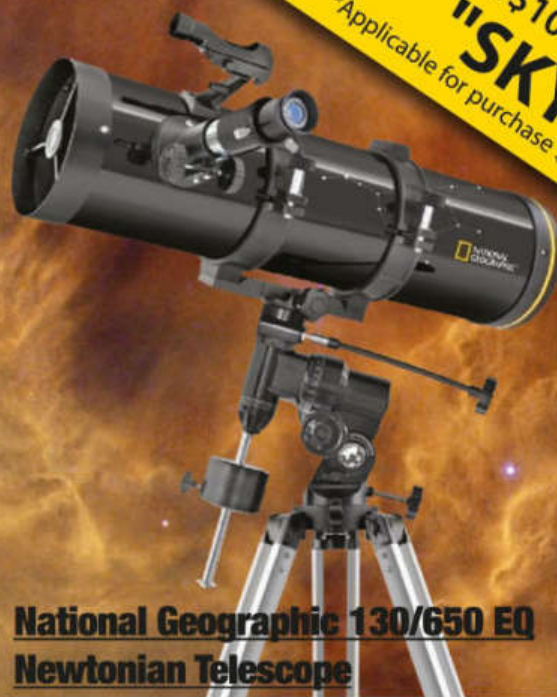
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THE CLARK / Now 127 years old, the 0.9-metre Clark is still one of the world's largest refractors. Astronomers use the telescope for occasional research and public outreach.

UCOP to return to teaching at UC Berkeley. A few months later, adaptive optics pioneer Claire Max (UC Santa Cruz) became UCO interim director. “From the very beginning, the UCOP provost [Aimée Dorr] and I established a strong working relationship,” Max says. “We looked at each other and said, ‘Let’s make this work.’” Max and her team developed a budget plan the provost accepted. On October 29th, UCOP rescinded its decision to defund Lick.

As soon as UC was a partner again, donations for Lick began materialising — first US\$300,000 from the Heising-Simons Foundation in December 2014, to upgrade the Shane reflector’s Kast Spectrograph, then in February 2015, US\$1 million over two years in unrestricted funds from Google.

Strategic planning

Lick emerged with an annual budget from UCOP of US\$1.5 million, down from

about US\$2.5 million a half decade earlier. “UCOP put a base under us, so it’s now possible to go after the money we really do need,” Max says. UCO is working to publish a strategic plan this year that will focus on a twin path: education and public outreach, and forefront science.

Outreach plans include expanding the summer visitor programs and the popular Music of the Spheres concerts, designing a self-guided walking tour of the mountain and telescopes, and renting out the beautiful marble main building and wood-paneled Clark refractor dome for weddings. Additional revenue options under consideration range from selling telescope time to non-UC researchers and entities to exploring the potential of corporate retreats and astronomical or nature tourism. Also in the mix are plans for greater involvement with local schools and renovating exhibits in the main building. A long-term dream is a major visitor’s centre.

Regarding forefront research, Lick is focusing on projects that can make good use of its medium-size instruments. UCO is now sorting through suggestions for 16 long-duration survey projects of three different types: continuous examination of the same objects night after night for a year or longer (such as the APF), ‘cadence’ projects that would examine a large number of objects at a set frequency (several times per night or several nights apart), and ‘targets of opportunity’ projects for transient events such as gamma-ray bursts and supernovae. Meanwhile, the second generation of laser guide-star adaptive optics just installed on the Shane reflector has resolution “as sharp as the Hubble Space Telescope!” exclaims former UCO interim director Sandra Faber (UC Santa Cruz), keeping that instrument viable for research for years to come.

“We’re not out of the woods yet,” cautions Filippenko. “We can’t declare



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victory, because we'd like Lick to live not just at the subsistence level." He feels he will not be able to rest until Lick's long-term future is secured with an endowment of US\$30 million to \$50 million: the annual interest on \$30 million would be about \$1.5 million, enough for "Spartan core operations," but annual interest from \$50 million would be closer to the former \$2.5 million, enough to expand, add new instrumentation, and do or even define cutting-edge research, he says.

Notes to self, lessons for others

Lick is not alone. Other well-known US observatories facing funding challenges include McDonald, Lowell and Mount Wilson. Outside the US, Subaru will suffer a major budget cut to enable Japan to be a partner in TMT, and other countries are choosing between funding successful but smaller-aperture telescopes and the next generation of superscopes.

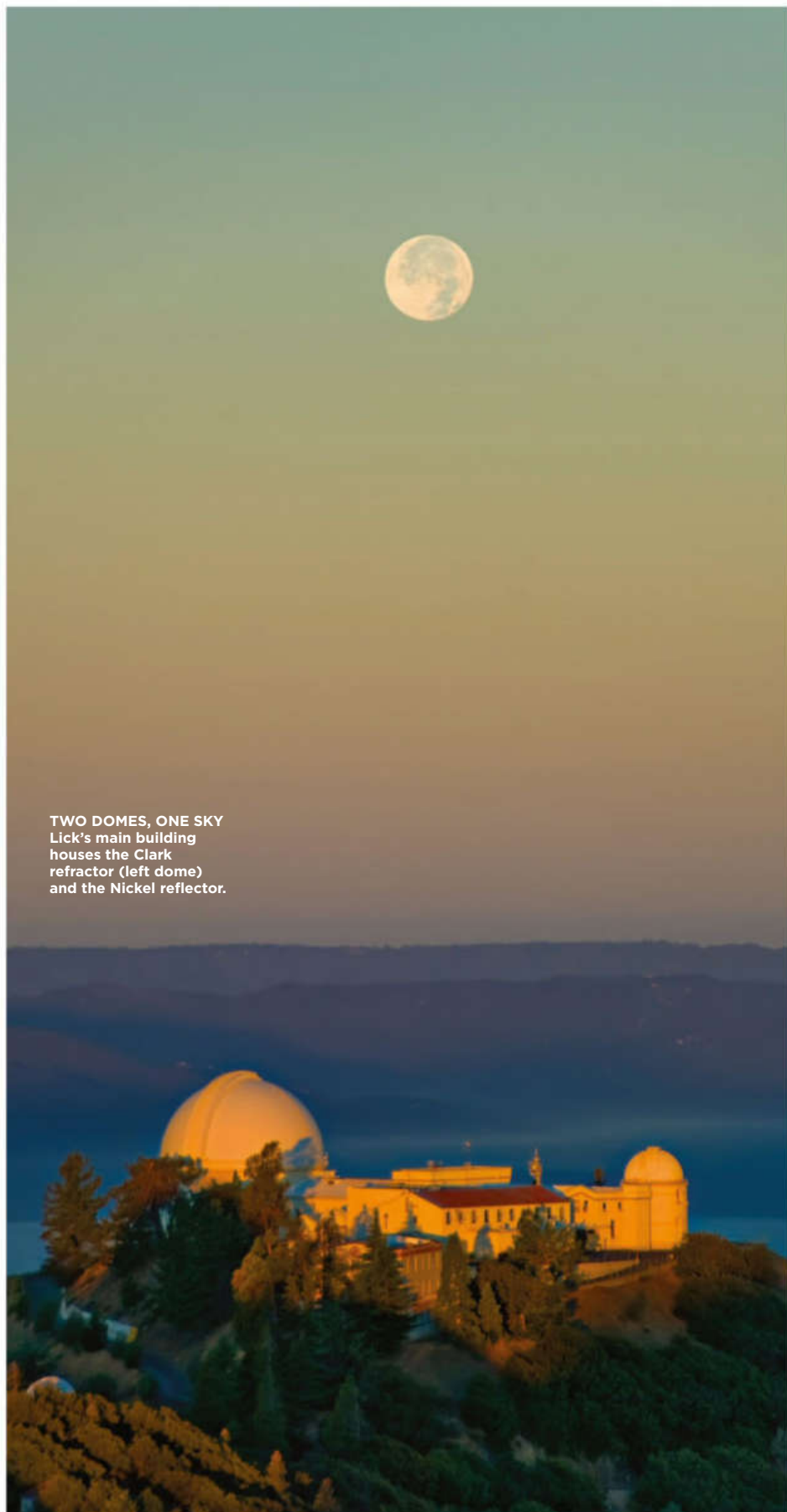
But medium-sized instruments are essential to astronomy. What many projects require is not aperture but time, Max says. Astronomers need long-term monitoring of hundreds or even thousands of objects to catch transient phenomena or to understand how common individual objects are in the universe, projects prohibitive on the biggest telescopes because telescope time is so precious. "Keck time is valued at US\$100,000 per night," said Kibrick. Time at Lick can be less than 10% of that.

With smaller telescopes, astronomers can try riskier projects that might not get approved at the largest instruments. Moreover, telescopes of 1 to 4 metres' aperture offer graduate students and postdocs — whom Keck and most other big observatories will not allow to be principal investigators — essential experience in proposing original projects and working with research-class instruments. "That's how a student becomes a grown-up scientist," Max says.

Another lesson: emphasise unique assets. Near-infrared emission from atmospheric hydroxyl (OH) molecules intensifies toward the equator, so for near-infrared astronomy at wavelengths of 1 to 2.5 microns, Lick at mid-latitudes actually has a darker sky than the Keck scopes in Hawai'i, Faber says. At these wavelengths, telescopes can see through interstellar dust and into regions hidden at visible wavelengths, ranging from star-forming nurseries such as the Orion Nebula to the centers of distant galaxies.

Importantly, not all the lessons from Lick's redemption are merely about demonstrating relevance in astronomy. Part of Lick's success has come from cultivating support over many constituencies: faculty, students, former students, astronomers, historians, educators, media, local governments, federal politicians and the general public. As Faber sums up, "Your continued existence depends on people's caring about you." ♦

Trudy E. Bell is a former editor for Scientific American, former senior editor for IEEE Spectrum magazine. In addition to the people quoted, the author thanks former UCO director Michael Bolte, UCSC astronomer Garth Illingworth, Lick Observatory staff astronomers Elinor Gates and Paul Lynam, and UCO astronomer Graeme Smith. Steven Beckwith was interviewed for 75 minutes, but later requested not to be quoted.



TWO DOMES, ONE SKY
Lick's main building houses the Clark refractor (left dome) and the Nickel reflector.



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Earth's Come & Go Moons

Astronomers are on the lookout for a smattering of tiny asteroids that get trapped as temporary moonlets around our planet

The interplanetary space surrounding Earth and its Moon is vast, but it is not completely empty. We're regularly visited by near-Earth objects (NEOs) that go unseen, except by those observers who spend their nights looking for them.

Now a handful of planetary scientists is hoping to find a tiny subset of these NEOs that actually become Temporarily Captured Orbiters (TCOs) — 'mini-moons' that are snared by Earth's gravity, linger in our vicinity for a few months or a few years, and then slip away.

The earliest known written mention of potential Earth-captured mini-moons came in 1913, when Clarence Chant, a University of Toronto astronomer, coordinated visual accounts of a dramatic North American meteor procession on February 9th of that year. Chant noted that these objects were "probably in an orbit about the Sun, and that on coming near the Earth they were promptly captured by it."

To date, the only known mini-moon was the small asteroid 2006 RH120. Likely only 3 to 7 metres across, this asteroidal fragment was discovered on September 14, 2006, with the Catalina Sky Survey's 0.68-metre Schmidt telescope on Mount Bigelow in Arizona. Dynamicists' reconstruction of its movement suggests that the interloper remained a tiny 'second moon' for about a year.

Snared by special circumstances

If astronomers discovered one by accident, there surely must be others. The first computer modeling to offer a plausible mechanism by which these mini-moons could become bound objects was put forth by Mikael Granvik (University of Helsinki, Finland) and others in 2012. Their simulations indicated that on average these objects make about three complete revolutions around Earth and stay captured for only 9.5 months. Only about 1% of them strike Earth.

It turns out that NEOs can only rarely become mini-moons. Those that do typically take up residency after passing through one of two gravitational 'sweet spots' known as Lagrangian points. L1 is situated about 1.5 million kilometres away from Earth in the sunward direction, while L2 is at the mirror image location in the direction opposite the Sun. Any two-body system (Earth and Sun in this case) has five such points at which objects can remain in a stable configuration relative to the two bodies for long time periods.



BRUCE DORMINEY

STEALTHY COMPANIONS
Astronomers estimate that, at any given time, Earth has up to 100 very small asteroids (at least 20 centimetres across) in temporary orbits around it. ILLUSTRATION BY DAN DURDA

To become mini-moons, objects must pass through L1 or L2 slowly — moving only 1 to 2 km per second (about 3,600 to 7,200 kph) with respect to Earth. (In contrast, uncaptured NEOs often zip by at tens of kilometres per second.) Then they ‘fall’ into the Hill sphere, the dynamical ‘netherland’ where our planet’s gravitational influence exceeds that of the Sun. Earth’s Hill sphere is about 1.5 million km in radius, some four times the Earth-Moon distance.

Granvik and his team estimate that, at any given time, there are probably about 100 mini-moons larger than 20 centimetres in diameter, a dozen at least 0.5 metre across, and one or two larger than 1 metre. An object the size of 2006 RH120, at least 3 metres across, might be captured only once every decade. Objects of 100 metres or more might show up only once in 100,000 years.

“Mini-moons typically lie from one to roughly 10 lunar distances on crazy trajectories around Earth,” said Robert Jedicke (University of Hawai‘i), one of Granvik’s coauthors. This distinguishes them from ‘pseudo moons’ that sometimes come close to Earth and even share our planet’s heliocentric orbital plane but are never gravitationally snared. In contrast, mini-moons are bona fide bound satellites — at least during the time they’re captured.

Bits of the early Solar System

The starting point for all mini-moons is almost certainly the main asteroid belt, explains dynamicist William Bottke (Southwest Research Institute). Basking in sunlight, these main-belt objects heat up and then re-radiate that energy, producing subtle forces that cause them to move slightly and their orbits to evolve gradually. These gentle nudges, combined with the long-term gravitational influences of Jupiter and Mars, cause a small subset of asteroids to migrate inward to establish Earthlike orbits.

However, only a tiny fraction are moving in just the right direction and slowly enough to be captured. “Some objects may stay a year, some may stay 20 years,” says Bottke. “They rattle around the Hill sphere with all sorts of trajectories until they find a way out. But it’s a steady-state population; for every one that leaves, one enters. And although there’s no restriction on size, over the next 100 years, we might only have one 20-metre mini-moon.”

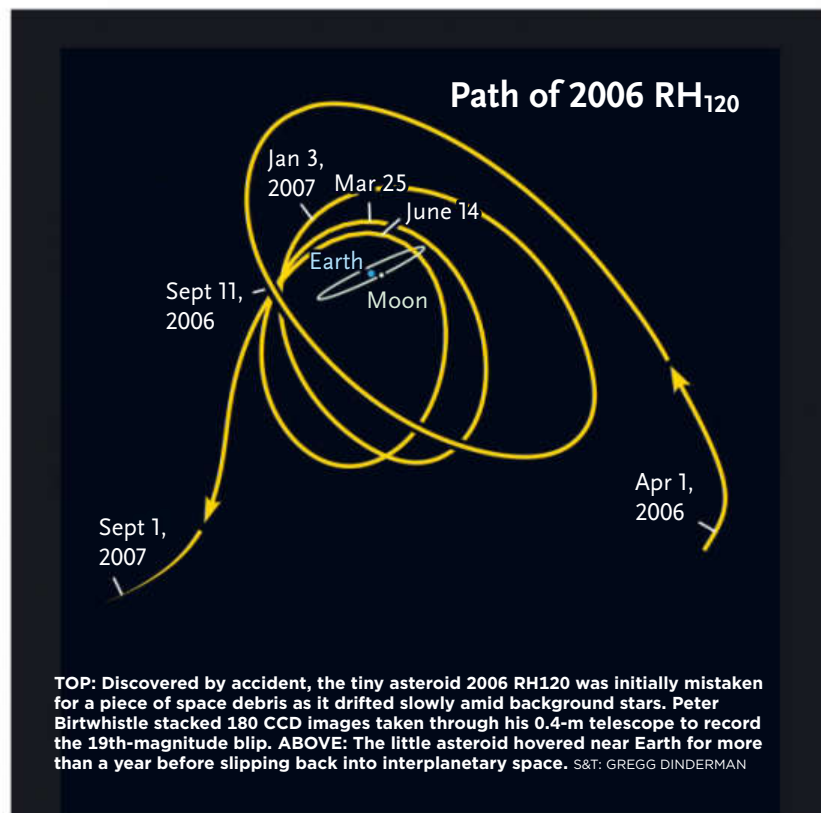
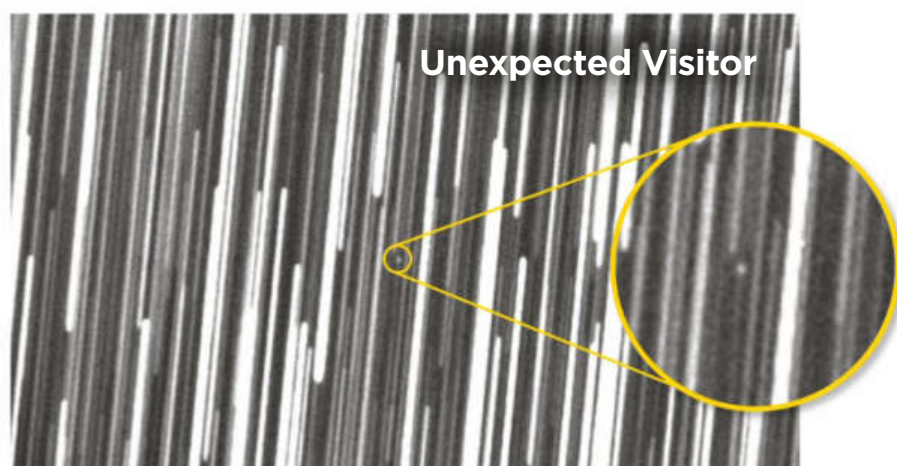
Once freed from the confinement of

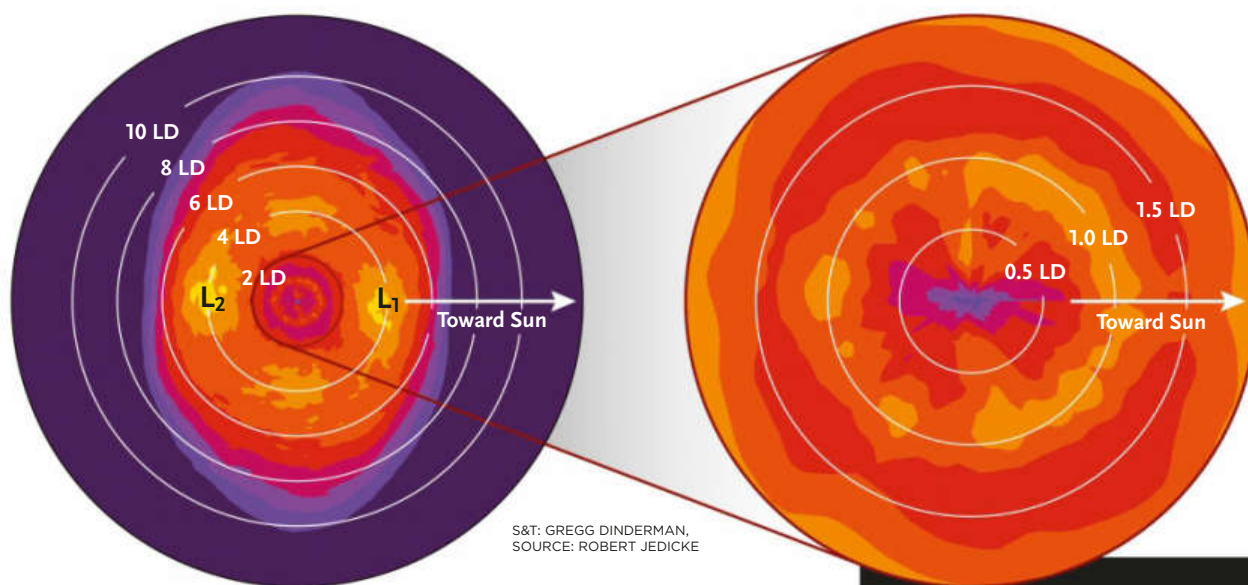
Earth’s gravity, they continue on nearly Earthlike heliocentric (‘Sun-centred’) orbits, with most unlikely to come close to Earth again for decades or even centuries.

Such small objects offer planetary scientists one of their best near-term hopes of bringing back a whole chunk of the pristine early Solar System. What makes them attractive as targets is that, unlike a random NEO zipping quickly past Earth, these mini-moons are not only orbiting nearby but also traveling at much lower relative velocities than other asteroids. (In fact, for a time

astronomers thought that slow-moving 2006 RH120 was actually a large chunk of spacecraft debris.)

This means that future space missions would require relatively modest rocket propulsion to reach any given object and return with samples of it — or perhaps to bring back the entire space rock. To get to a main-belt asteroid requires more powerful rockets than to get to some NEOs. And mini-moons offer the best economy of all, because they’re relatively close by. One scheme involves having a spacecraft ‘parked’ in geosynchronous orbit that could be





dispatched on short notice to rendezvous with a captured object. Then it could retrieve the object wholly intact for transport as cargo back to Earth-based laboratories for analysis.

A challenge to find

Predicting that mini-moons exist is one thing, but spotting such small bodies is a very different matter. A 2014 analysis by Bryce Bolin (University of Hawai'i) and others concludes that the planned Large Synoptic Survey Telescope (lsst.org) should be capable of discovering one of them per month, though it's not clear how they'd be flagged as mini-moons or tracked after discovery. Jedicke thinks to truly chart these objects' orbits and dimensions will

require a dedicated space telescope.

To that end, in early 2013 he proposed dedicating one of two 2.4-m space telescopes, which the US National Reconnaissance Office had recently donated to NASA, to the detection of these objects from the Earth-Sun L1 point. The 5-year effort he envisioned would perform a deep survey for objects throughout the Solar System that were moving along the ecliptic plane. It would identify a wide array of objects beyond mini-moons: imminent Earth impactors, other NEOs, main-belt asteroids, comets, Trojans (objects that share Jupiter's orbit), Centaurs (renegades from the Kuiper Belt) and trans-Neptunian objects.

It seemed like a great fit at the time: NASA was seeking a target for its proposed Asteroid Redirect Mission,

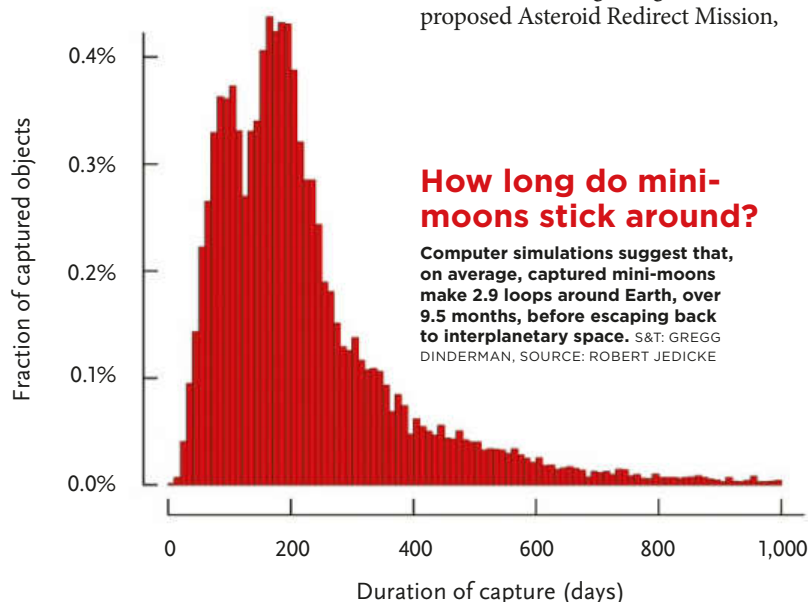
Top-Down View

These plots show a computer simulation of the distribution of mini-moons near Earth averaged over time, with yellow denoting the highest likelihood. They are captured by Earth's gravity after slowly slipping through one of two Lagrangian points, labeled L_1 and L_2 at left. The enlargement at right shows that several objects could lie inside the Moon's orbit (labeled 1.0 LD), but most are too small to detect even with powerful telescopes.

and mini-moons would be easy pickings, dynamically speaking. But ultimately space-agency managers cooled to the idea of using the donated space telescopes and also decided that the redirect mission would be designed to pluck a boulder from a largish NEO for astronauts to study, rather than to snare a whole small object. Besides, it's unrealistic to plan a spacecraft rendezvous with an object that hasn't been discovered yet.

Yet planetary researchers realise the immense scientific value of bringing an intact mini-moon back to Earth for study. They point to the celebrated case of 2008 TC₃, which to date is the only asteroidal object detected by observers before impacting Earth. Roughly 3 metres across, it broke up in the atmosphere over the northern Sudanese desert, and search teams later recovered samples from the ground. Although the impactor was not a mini-moon, its composition proved unusual.

"TC₃'s meteorites are largely ureilites, a weird set of rocks from a body that



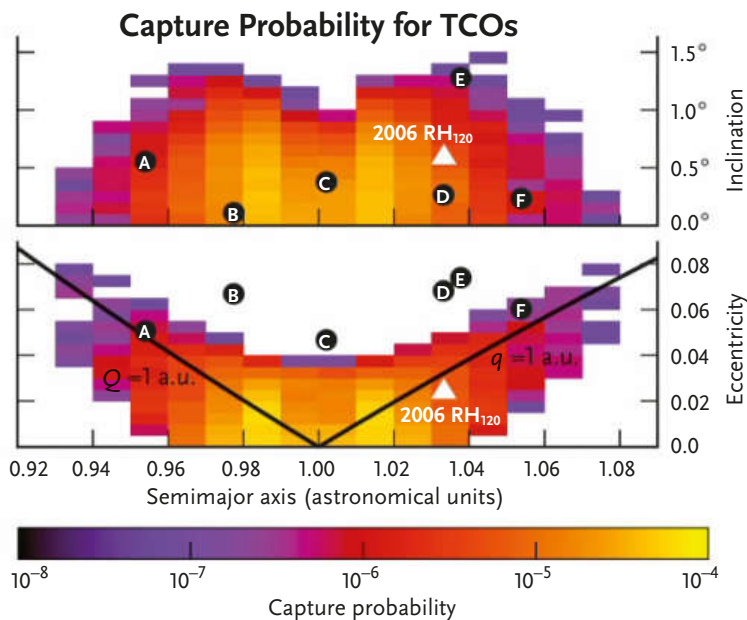
melted and was then blown to smithereens a few million years after it formed,” says geochemist Ed Scott (University of Hawai‘i). “Some of its centimetre-sized samples contain totally different kinds of meteorites from very different main-belt asteroids. We still don’t understand how it acquired them.”

The hope is that small mini-moons might also have similarly interesting compositions. In fact, finding them on a regular basis would allow astronomers to spot and track potential Earth-impacting mini-moons well in advance. Were one predicted to slam into our atmosphere, researchers could set up a system to photograph, take spectra of, and measure a true bolide.

“With a month’s notice, you could have people all lined up to observe the object coming through the atmosphere,” says planetary scientist Clark Chapman (Southwest Research Institute). “You would know where it will hit, then have people find the fragments. The whole body of meteor spectra that sits in the literature could be reinterpreted with much more confidence. It would be TC3 ten times over.”

Some researchers, including Granvik, would like to use mini-moons to determine whether small asteroids have interiors that are more akin to rubble piles than solid pieces of space rock. This would have consequences for strategies to mitigate Earth impactors, as well as for future robotic and human missions to small asteroids.

But there’s also more fundamental science at stake. “The way to understand



In order to become captured, an asteroid must have an orbit very similar to Earth’s, both in terms of its inclination (top panel) and eccentricity (lower panel). Colour coding shows the probability of capture, with yellow denoting most likely, and the black lines indicate orbits with aphelia (Q) and perihelia (q) of 1 astronomical unit. Paired letters identify known asteroids whose orbits make them susceptible to capture, though none have been. Also shown is the pre-encounter orbit of asteroid 2006 RH₁₂₀, the only known mini-moon to date.

how the Solar System formed,” says Jedicke, “is to bring back chunks of it that haven’t been processed by tumbling through Earth’s atmosphere or by surface weathering.” The end result would provide what Jedicke terms a veritable set of “Rosetta stones” from which to unravel the Solar System’s earliest history.

The first step is simply to find them. “Right now it’s just theoretical, not a viable population,” Jedicke admits. But

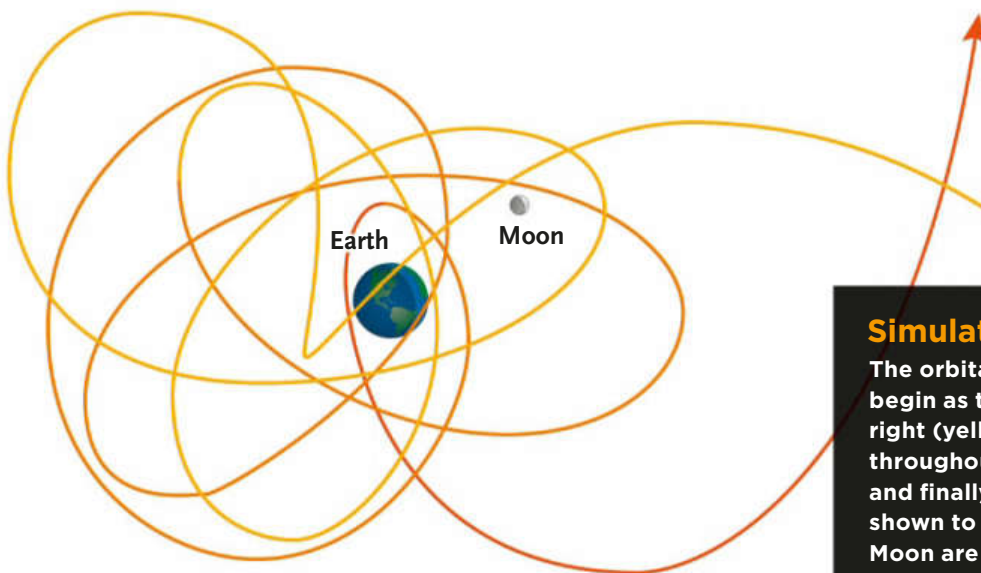
the hunt is on — he’s recently secured observing time on Japan’s 8.2-m Subaru Telescope and its sensitive, wide-field detector called Hyper Suprime-Cam. Statistically, Jedicke figures he’s got a 40% chance of finding a mini-moon during a single night and as high as 90% if he can squeeze in five nights of observations spread over a few months. “I’ve devoted a lot of time to understanding these objects,” he says, and if the Subaru effort succeeds, he’ll finally have a real mini-moon or two to work with. ♦

Robert Zimmerman posts regularly on his website, behindtheblack.com, on science, technology, politics and culture.

K. TERAMURA / UNIV. OF HAWAII

Simulated mini-moon trajectory

The orbital gyrations of a simulated mini-moon begin as the object approaches Earth from the right (yellow line), makes several irregular loops throughout the Earth-Moon system (orange) and finally escapes (dark orange). Distances are shown to scale, but the sizes of the Earth and Moon are not.



**NEEDLE IN A
HAYSTACK**
The nearest star to
the Solar System,
Proxima Centauri
(arrowed), is a
faint red dwarf,
not far (in stellar
terms) from
the far brighter
binary star
Alpha Centauri
(overexposed at
top left). ESO

Promixa Centauri

Meet the neighbour

On 12 October 1915 a circular from the Union Observatory in Johannesburg, South Africa reported the discovery of a faint star with an exceptionally fast angular motion across the sky. Robert Innes, the director of the Observatory, had discovered what was to become known as Proxima Centauri, the closest star to the Solar System.

The discovery

Most stars are so far away that their positions in the sky do not seem to alter. Innes, who as we will see later had strong Australian connections, was interested in finding stars with large proper motions, that is, ones with large angular motions across the sky. These stars are of interest as they are likely to be relatively close to our Solar System.

To search for such stars, Innes decided to look in the vicinity of the double star Alpha Centauri, which was then the closest known star to the Sun. Using a device called a blink comparator, he examined two photographic plates of the region, both taken by his chief assistant Harry Wood — one taken earlier in 1915 and another from five years before. A blink comparator allows two plates to be carefully

aligned and then small areas to be compared by switching the view in a microscope from one plate to another. During 'blinking', most stars appear stationary, while one with a large proper motion will seem to jump from one position to another. The most famous user of a blink comparator was Clyde Tombaugh, who in 1930 used one at the Lowell Observatory in Arizona to discover Pluto.

Examining the plates was hard work for Innes, as they were from the observatory's Franklin-Adams survey camera, which recorded a very wide 15° by 15° region of the sky. Even by limiting the search to the inner 60 square degrees on the plates, the number of stars to look at was so large that it would take about 40 hours. So to reduce the severe eye strain involved in 'blinking', he spread the search out over a fortnight. Adding to the difficulties was that the original of the 1910 plate had been sent to Greenwich Observatory in the UK, so he had to work with a copy that had slightly distorted star images.

Once Innes spotted the star, its motion in the five years between the plate exposures was measured to be 4.9 arc seconds in a direction on the sky indicated by 289°. Intriguingly,

One hundred years ago the closest star to our Solar System, Proxima Centauri, was discovered deep in the southern skies.

this measured value and direction were similar to those of Alpha Centauri. Were the stars connected despite being separated by over 2° in the sky?

Determining distance

The possible link to Alpha Centauri made it important to measure the



NICK LOMB

distance or parallax of the newly found high-proper-motion star. When astronomers measure the distance of a nearby star they actually measure its parallax, which is the angle between the star, Earth and Sun, using the Earth-Sun distance as a baseline. The accepted value for the parallax of Alpha Centauri at that time was $0.759''$, which puts the distance at 4.30 light-years.

Although the Union Observatory had a 9-inch (23-cm) Grubb lens telescope that was suitable to make the parallax measurement of the new star, it lacked the necessary micrometer eyepiece to measure the angles between stars to the required precision. So one was quickly ordered and it arrived in May 1916. In the meantime Dutch astronomer Dr Joan Voûte, working as a volunteer assistant, began a photographic determination of the parallax at the Royal Observatory in Cape Town. His (the appropriate pronoun despite his first name) results, published in 1917, placed the new high-proper-motion star at essentially at the same distance as Alpha Centauri.

Innes measured the parallax of the star visually using the micrometer eyepiece. He also measured the star on three Sydney Astrographic plates that William Cooke, the Government Astronomer at Sydney Observatory had provided to him for the purpose. Combining his results and averaging them with those of Voûte, plus with a calculation based on proper motions, Innes came up with a mean of $0.784''$ for the parallax of the star. This value placed it somewhat closer than Alpha Centauri, leading him to name the star Proxima Centauri (although he actually incorrectly called it Proxima Centaurus).

Who was Robert Innes?

Robert Thorburn Ayton Innes arrived in Sydney in 1890 as a 28-year-old to set up a wine and spirit business. Born in Edinburgh and having studied in Dublin, he developed such a strong interest in the mathematical aspects of astronomy and had such an aptitude for it that he became a Fellow of the Royal Astronomical Society at the surprisingly young age of 17.

In Sydney he set about making himself known to local astronomers. He started by visiting Sydney

Observatory and meeting with its director, Henry Chamberlain Russell. A few months later he went out to Windsor to meet the famed amateur astronomer John Tebbutt. Soon he also met other local amateurs such as Walter Gale, who was just four years younger than Innes and later became a leader in Australian astronomy. An important joint activity by Innes and Gale was the founding of the New South Wales Branch of the British Astronomical Association. This Branch has survived to the present day, and earlier in 2015 celebrated its 120th anniversary under the new name of Sydney City Skywatchers.

Innes continued his researches in mathematical astronomy but, influenced by Gale and Tebbutt, he obtained a telescope and also began astronomical observing. Once he built up his observing skills he started on a systematic search for double stars. He was successful in his searches, as shown by a paper published in the *Monthly Notices of the Royal Astronomical Society* listing 26 double stars, of which he had discovered all but four. In early 1895 he began using a larger aperture telescope of 42-cm aperture that he had commissioned. This telescope allowed him to search for fainter stars and he found another 16 doubles. He also began to compile a catalogue of double stars by combining his own observations with those of Gale and other Southern Hemisphere observers. Though it took a while for that catalogue to be published, it became an important resource for observers of the southern sky.

The move to Africa

Astronomy was now such a major part of Innes' life that he became keen to abandon commerce and work full time as an astronomy professional. After failing to obtain the position of Government Astronomer for Western Australia, he accepted a basic clerical position at the Royal Observatory at the Cape of Good Hope in South Africa. David (later Sir David) Gill, director of the observatory, was familiar with Innes' published papers but asked John Tebbutt for assurances that 'in a social and moral point of view his habits of life are beyond reproach'. Tebbutt happily gave those assurances and in February 1896 Innes



DISCOVERER
Robert Innes
at the Union
Observatory
with part of the
blink comparator
visible behind
him. Courtesy of
the South African
Astronomical
Observatory.

and his family sailed for South Africa.

At the Royal Observatory Innes had a responsible and multifaceted position as secretary, book-keeper and librarian. Though his official duties did not include astronomy, in his spare time he could use the observatory's telescopes to continue observing double stars as well as comets, variable stars and occultations of stars by the Moon. Gill must have been impressed with Innes' skill and enthusiasm for, when the South African government decided to set up a new observatory in Johannesburg, he supported the appointment of Innes as director.

When Innes took up his position in 1903, the new Transvaal Observatory was concerned only with meteorology. Soon, however, telescopes were acquired so that astronomy also became possible. In 1912 the meteorological work was transferred elsewhere and the observatory, now called the Union Observatory, became purely an astronomical one. Innes and his observatory then concentrated on studying the proper motion of stars, double stars and phenomena associated with Jupiter's satellites.

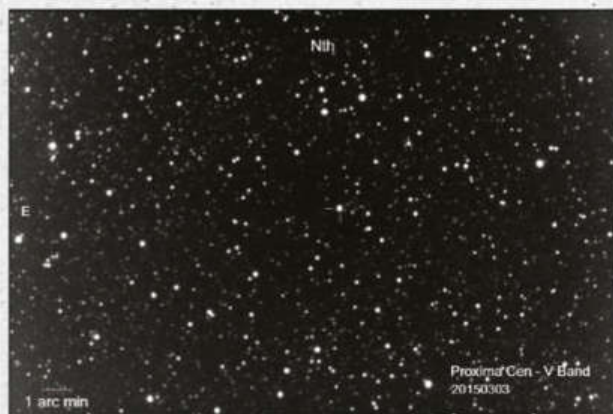
Robert Innes became internationally recognised for his contributions to astronomy and in 1923 Leiden University in the Netherlands awarded him an honorary Doctor of Science degree. Four years later he retired from the Union Observatory and died in 1933.

What do we know of Proxima?

Thanks to the work of the European HIPPARCOS satellite, the parallaxes of Alpha Centauri and Proxima Centauri are known to a good



PROXIMA PORTRAIT This is Proxima Centauri, as seen by the powerful Hubble Space Telescope. ESA/HUBBLE/NASA



NOTHING SPECIAL Proxima Centauri is a non-descript 11th-magnitude star in the southern skies. Courtesy Peter Nelson.

accuracy. They are 0.755" and 0.772", respectively, equivalent to distances of 4.32 and 4.22 light years. These values place Proxima a little further from the Earth and closer to Alpha Centauri than Robert Innes had assumed in 1917. Still Proxima remains the closest star to Earth (if we ignore the Sun, of course).

From the first, Innes assumed that there was an association between Proxima and the double star Alpha Centauri to which it is close and with which it shares a very similar motion in space. Most scientists debating the stars have continued to assume that Alpha Centauri is a triple system, with Proxima making a slow orbit

around the more visible close pair. On current values the calculated orbital path is highly elongated and comet-like, stretching across a distance over 540,000 times that of the Earth from the Sun. Such a huge orbital path is impossible, as it would be disturbed by the gravitational pull of the rest of the Milky Way galaxy. However, as astronomers improve their measurements in the future it is possible that an orbit will be found in which the gravity of the close pair does just manage to grip Proxima. At present we cannot be certain if that is the case.

Proxima Centauri is a low-mass reddish dwarf star of spectral type M. Its width is only 14% that of our Sun and its mass is estimated at 12% of that of the Sun. The light emitted by the star is so low that even at its close distance it has a brightness of only 11th magnitude, which is 100 times too faint to be seen by the unaided eye from a dark site. A reasonably large telescope is needed to see it by eye, and even then it is a challenge to identify it among the many other stars of similar brightness in the field of view.

An important aspect of Proxima Centauri is that, like many other M-type stars, it is a flare star. That is, its brightness can considerably increase over a period of a few minutes. These dramatic brightenings are believed to be due to explosions on the stars' surfaces, similar to flares on the Sun. A typical solar-sized flare would have a much greater impact on the observed magnitude of a low-intrinsic-brightness star like Proxima. Flares on M-type stars occur randomly at intervals ranging from hours to days apart, with the possibility of multiple flares occurring at the same time. The source of the energy for the flares is believed to lie in interactions between the magnetic fields of the stars, their spin and the turbulent motion in their outer layers.

Proxima releases a large part of its flare energy in the form of X-rays. This means, of course, that if there are any planets circling the star this is bad news for the potential of finding any form of life on them. Still, since the star is relatively close to us astronomers have made extensive searches for any associated planets. Searches have been made with the Fine Guidance Sensor on the Hubble

Space Telescope and also with ground-based telescopes, looking for any wobbles in the motion of Proxima due to the influence of planets. As well, the velocity of the star in the line of sight (radial velocity) has been examined for the fluctuations that would indicate short-term orbital motion. No planets have been found so far, and the possibility of Jupiter-sized planets with orbital periods of less than 12 years has been eliminated.

There are also rare opportunities to look for planets through gravitational microlensing. As seen from Earth, Proxima passed close to a much fainter background star in October 2014 and will pass even closer to a similar star in February 2016. During these alignments, Proxima's gravity bends the light from the more distant star, as will the gravity of a putative Proxima planet. Observations at the right time should yield a measurement of the mass of Proxima and could lead to the discovery of a planet or two, if they are there.

Getting closer

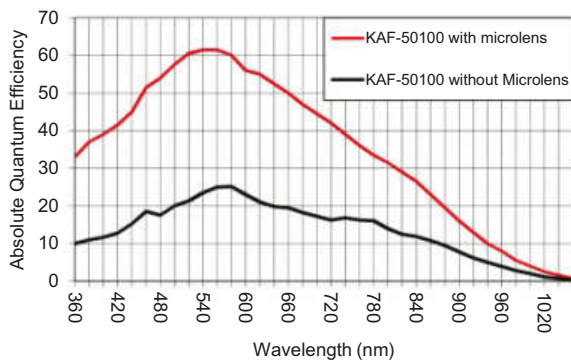
No star closer than Proxima Centauri has been discovered so far. Proxima is moving towards the Sun, but it will take 27,400 years for it to reach its closest point to the Solar System. At that time it will be just 2.9 light years away, with the close pair of Alpha Centauri following closely behind.

Eventually, Proxima will be replaced as the closest star by another faint M-type star, Ross 128, although that star will only approach as close as 6.3 light years. According to Russian astronomer Vadim Bobylev, the closest approach to the Sun that we can foresee will be by a K-type star called GL710, which is about half the mass of the Sun. In about 1.5 million years it is likely to pass at a distance of one light year or less, so close that it will disrupt the Oort cloud of comets surrounding the Sun and possibly send a host of comets into the inner solar system. If our descendants are still around they will need to take care! ♦

*Nick Lomb is the former Curator of Astronomy of the Sydney Observatory. His 2016 *Australasian Sky Guide* will be available in November. He thanks Wayne Orchiston for his 2001 research paper on the life of RTA Innes in the *Publications of the Astronomical Society of Australia*.*



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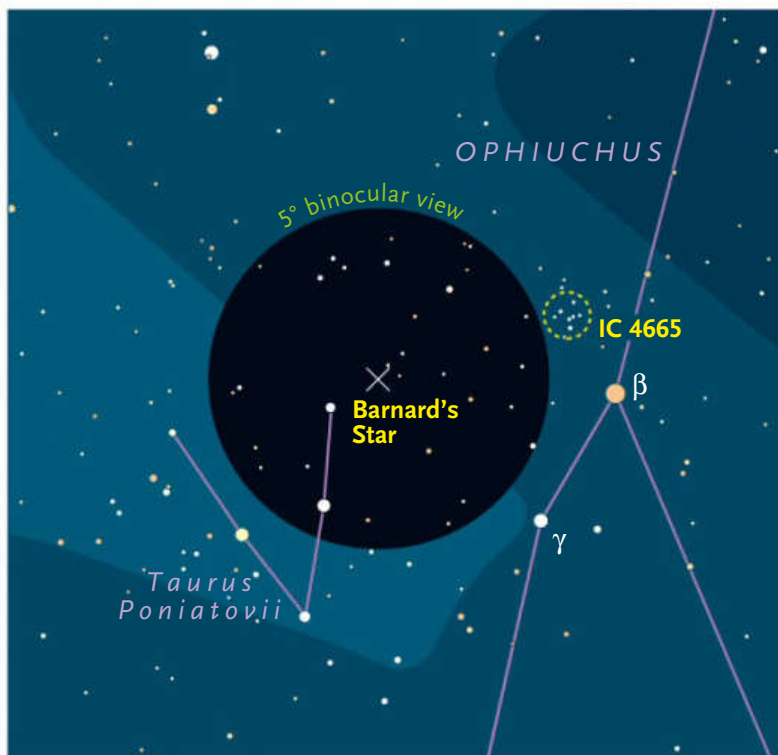
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A trip to Barnard's Star

One of the most memorable events of my childhood was a visit to a planetarium where they were presenting a programme on the possibility of planets beyond our Solar System. It was a wondrous idea in the late 1960s, but one that was still unproved. And yet, even to a child, it just seemed so probable. The exoplanet excitement of the day was fueled by an obscure dot of light in Ophiuchus known as Barnard's Star. And though its wobbling motion — initially taken as evidence for an unseen planetary companion — turned out to be the product of instrument error, Barnard's Star is nonetheless remarkable. It lies only 6 light-years away, which makes it second only to the Proxima/Alpha Centauri system (see page 36). Its proximity contributes to its incredible proper motion — Barnard's Star moves the apparent diameter of the Moon every 175 years.

Sighting Barnard's Star with binoculars takes a little patience and care. Begin by locating the V-shaped asterism of 7th-magnitude stars known as Taurus Poniatovii, a lovely object in its own right. Use the chart above and proceed northwest from the western tip of the V to the location of Barnard's Star. The star itself is a magnitude 9.5 red dwarf. I have little trouble seeing it through my mounted 10×50 binoculars. Indeed, the greater challenge is sorting out which point of light is the correct one.

If Barnard's Star eludes you, or leaves you unsatisfied, head back to Beta (β) and enjoy the nearby, easy open cluster IC 4665 (see story, page 58). It's a fairly distinct gathering of about a dozen 7th- and 8th-magnitude stars. But in spite of the cluster's apparent proximity to Barnard's Star, IC 4665 lies comparatively far way at a distance of some 1,400 light-years. ♦

USING THE STAR CHART

WHEN

Early September	10pm
Late September	9pm
Early October	8pm
Late October	Dusk
These are standard times. Add 1 hour for daylight savings.	

HOW

Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front of you in the sky. The centre of the map is the zenith, the point in the sky directly overhead.

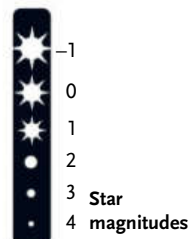
FOR EXAMPLE: Turn the map around so the label "Facing SW" is right-side up. About a third of the way from there to the map's centre is Crux, the Southern Cross. Go out and look southwest about a third of the way from horizontal to straight up. There's the Southern Cross!

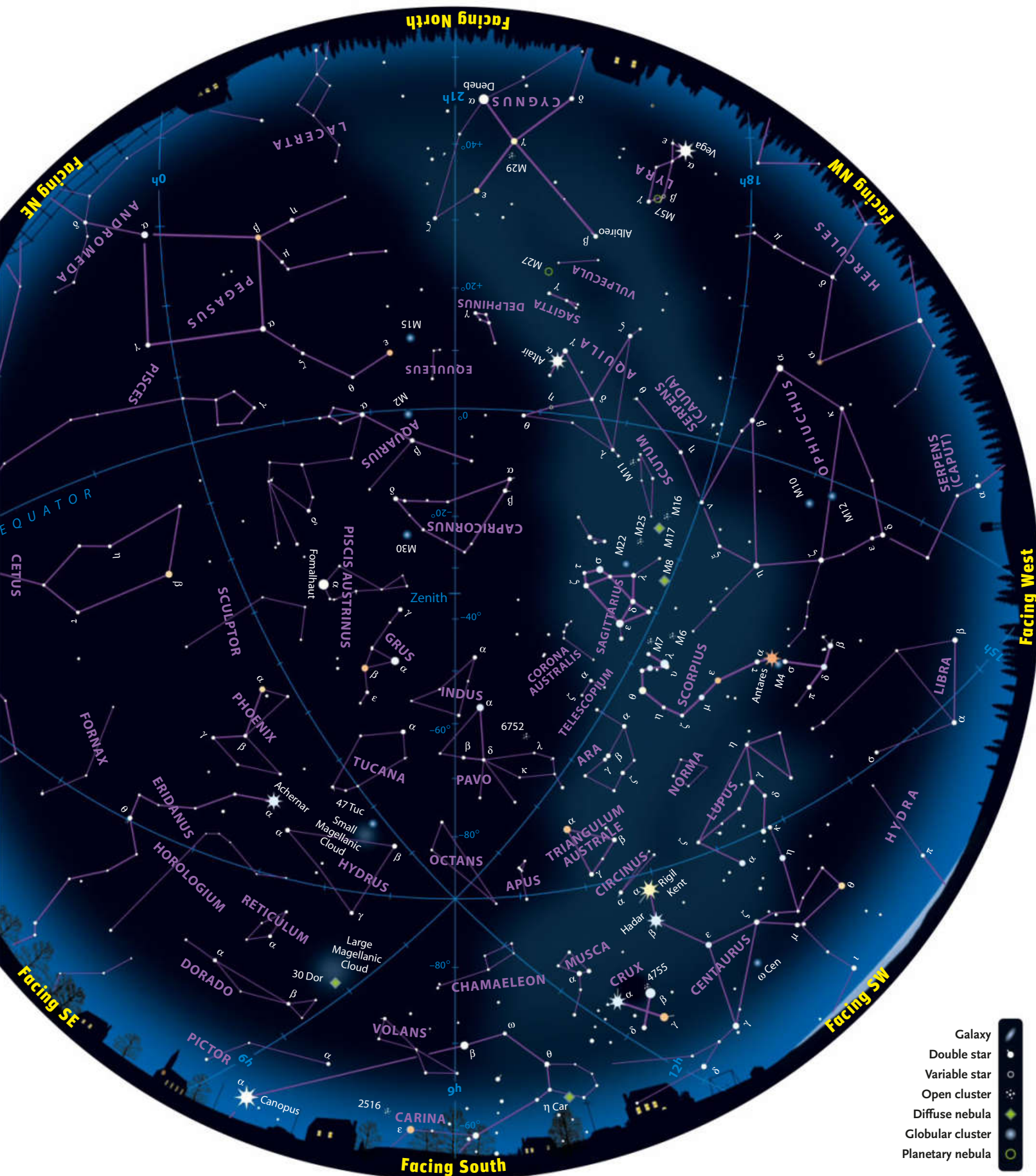
NOTE: The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're far north of there, stars in the northern part of the sky will be higher and stars in the south lower. Far south of 35° the reverse is true.

ONLINE

You can get a sky chart customised for your location at any time at SkyandTelescope.com/observing/skychart

Facing East







A triple-planet show

Venus, Jupiter and Mars tussle for position in the morning sky

Can you feel it? Summer is definitely on the way, as the weather becomes warmer and the nights a bit shorter. Depending on where you live, and therefore what sort of seasonal weather you have, this can be one of the best times of the year for stargazing.

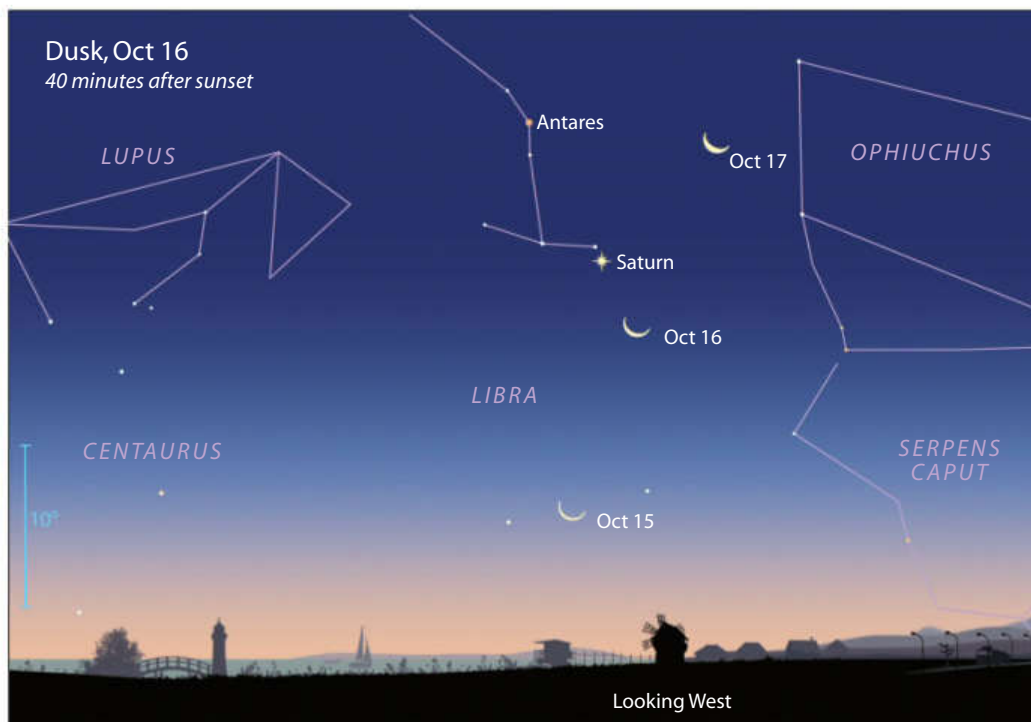
Let's start with the innermost planet, **Mercury**, which will begin October lost in the Sun's glare, but soon will appear in the morning sky. You'll have to look hard to see it, though, as it will be very low on the horizon.

Venus will be the star of the show this month, engaged in a merry tussle with two of its planetary siblings and an occultation by the Moon (see page 57). The bright planet will be visible to the east in the morning sky, shining at around magnitude -4.5 and with an apparent diameter of around 24 arcseconds. During the latter half of the month, Jupiter and Mars will be close by, forming an impressive triple-planet display (see diagram). On October 26, Venus and Jupiter will be just one degree apart — so stand by for reports of UFOs and other strange lights in the sky!

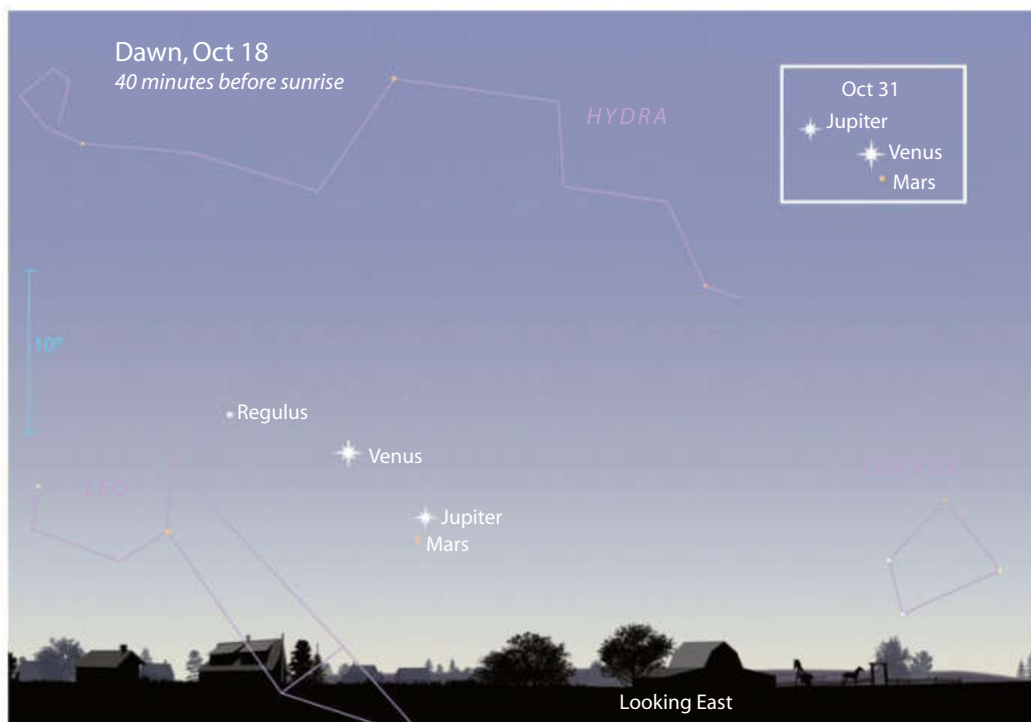
As mentioned, **Mars** will be visible to the east before dawn. The ruddy-coloured planet will be at magnitude 1.8 and, at just 4.1 arcseconds across, has a much smaller apparent diameter than Venus. Watch for the Moon nearby on the 10th, and then for a close encounter with Jupiter on the 18th, when the two planets will be less than half a degree apart.

Jupiter will shine at magnitude -1.8 in the morning sky, attempting to rival Venus in brightness but not quite making it. In size, however, it dominates, having an apparent diameter of a whopping 32 arcseconds. As mentioned above, the king of the planets will have two planetary neighbours nearby for the second half of the month. Grab your binoculars and see if you can make out any of the four Galilean moons — it shouldn't be too hard.

The ringed planet, **Saturn**, will be in the evening sky to the west after sunset, located near the head of Scorpius. There'll be a nice colour contrast between the planet's yellow-white and the star Antares' angry red. Watch for the very thin crescent Moon nearby on October 16 (see diagram).



Saturn will sit at the head of Scorpius after sunset on October 16, with the thin crescent Moon nearby.



Three planets gather in the dawn light on October 18. The inset shows how their positions will have changed by October 31.

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Events Of Note

Oct	2	Aldebaran 0.5° south of the Moon
	9	Venus 0.7° north of the Moon
	9	Regulus 3° north of the Moon
	10	Mars 3° north of the Moon
	10	Venus 3° south of Regulus
	10	Jupiter 3° north of the Moon
	16	Saturn 3° south of the Moon
	18	Jupiter 0.4° south of Mars
	24	Saturn 0.4° north of Beta Scorpii
	31	Jupiter 1° south of Venus

Times are listed in Australian Eastern Standard Time



October 2015

Phases

Last Quarter October 4, 21:06 UT
 New Moon October 13, 00:06 UT
 First Quarter October 20, 20:31 UT
 Full Moon October 27, 12:05 UT

Distances

Apogee October 11, 21h UT
 406,388 km
 Perigee October 26, 21h UT
 358,463 km



Celestial Calendar

Get set for the Orionids

Con Stoitsis

October heralds one of the year's best meteor showers

The great thing about meteor observing is that you don't need a telescope or binoculars — just a comfortable chair and some warm clothing. And one of the best annual meteor showers is only weeks away — the Orionids, so-called because its radiant — the point in the sky from which its meteors appear to originate — is in the constellation Orion. This puts it at a useful elevation for observing from most locations in the Southern Hemisphere.

This year the peak is predicted for the morning of October 22, and conditions will be favourable — the waxing gibbous moon will set a few hours before dawn, and not affect

observations. Start looking on the morning of 17/18 October, and conclude on the morning of the 23rd/24th.

From 2006 to 2009 the Orionids produced unexpectedly strong ZHRs of around 40 to 70. (ZHR stands for zenithal hourly rate, and is an indication of the number of meteors that could be expected to be seen per hour in perfect conditions if the radiant were at the zenith in pristine, dark skies.)

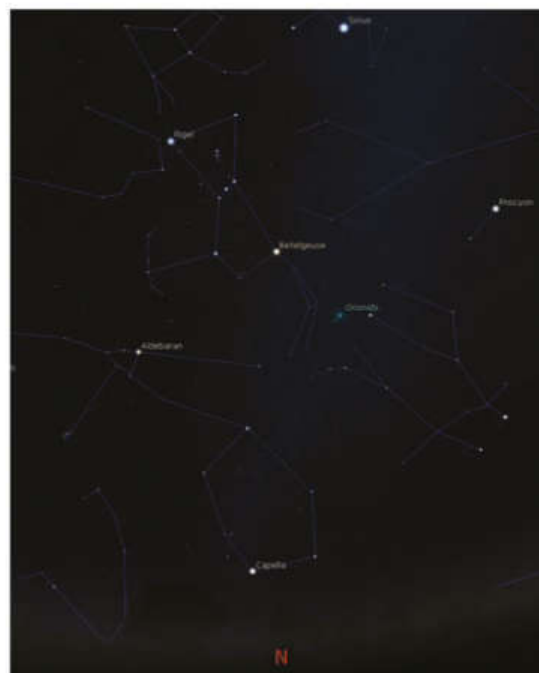
The International Meteor Organisation has published material over the years stating a periodicity of 12 years for this shower, suggesting the lower-activity phase of the cycle should fall between 2014 and 2016

— so rates may be close to their weakest this year and next. Predicted rates for 2015 are about 15 to 22 meteors per hour. But the Orionids often produces several lesser maxima, helping activity to remain constant for several mornings before and after the maximum.

Orionid meteors are often white in colour, leave persistent trains, and are of medium speed. The average magnitude is 2.4, and fireball and bolide activity is not often recorded.



Jamie Cooper snapped this image of a Perseid meteor in mid-August. The Perseids is a Northern Hemisphere shower.



Look for the Orionids in the morning hours between October 18 and 24. Maximum is expected on October 22.

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Return to the water carrier

Ross Gould

Double stars of western Aquarius

It was back in 2009 that this column last visited Aquarius, the water-carrier. This time we'll look at a further selection of doubles from the westernmost end of the constellation. Some of them don't have nearby bright guide stars, so finding them will need star-hopping with a good-sized optical finder and star map, or a Go To system.

Our doubles this time have STF designations, for F.G.W. (Wilhelm) Struve, regarded as the founder of systematic modern double star work. He was the first thorough surveyor of the northern and equatorial sky for double stars, in the 1820s and 1830s. Using Fraunhofer's 9.6-inch refractor, the first modern-quality refractor of good size, and equipped with an equatorial mount and driving clock, Struve first surveyed about 120,000 stars looking for doubles, then returned later to accurately measure the more than 3,000 double stars he'd recorded, down to declination -15° . His limit for wide pairs was $32''$. The original survey was done at such speed — examining up to 400 stars per hour — that some pairs within reach of his telescope were missed.

4 Aquarii, or **STF 2729**, is a bright binary with a 200-year orbit. The 6th- and 7th-magnitude stars are yellow, only $0.8''$ apart. Struve discovered it in 1829, and it has now returned nearly to the same point in its orbit. Ernst Hartung (*Celestial Objects for Southern Telescopes*, 1968) noted that the pair was at minimum separation, $0.2''$, early in the 20th century. When he observed it in 1960, it was in the widest part of the orbit at $1.1''$, and *15cm showed the stars clearly apart*. Separation has been decreasing since then, and will keep lessening until 2060. My 235-mm SCT showed them just apart at 235x; my 140-mm refractor showed the pair elongated, a notched image, at 285x.

Three degrees eastwards from 4 Aqr is **12 Aqr**, or **STF 2745**. This is a bright unequal double, with a colour contrast of yellow and white (Hartung), or yellow and "ocean blue" (Haas, *Double Stars for Small Telescopes*, 2006). It's a fine pair; with a 180-mm refractor, 90x showed a delicate close pair, also visible with smaller scopes. It's probably a very long-

period binary, and separation has decreased slightly over time.

Nearly 2 degrees east from 12 Aqr is **STF 2768**. With my 140-mm refractor at 80x, this was a middling-bright orange star with a small companion near, in a fairly starry field. A 100-mm scope will show it. Smaller scopes might have difficulty with the secondary star at mag 10.5.

STF 2744 can be found nearly 5 degrees SW of Alpha Equulei (mag 3.9). A moderately close and fairly bright pair, it's the middle star of three bright stars in an arc. My 140-mm refractor showed it as a just-separated pair at 160x, yellowish in colour (Haas calls them "lemony white").

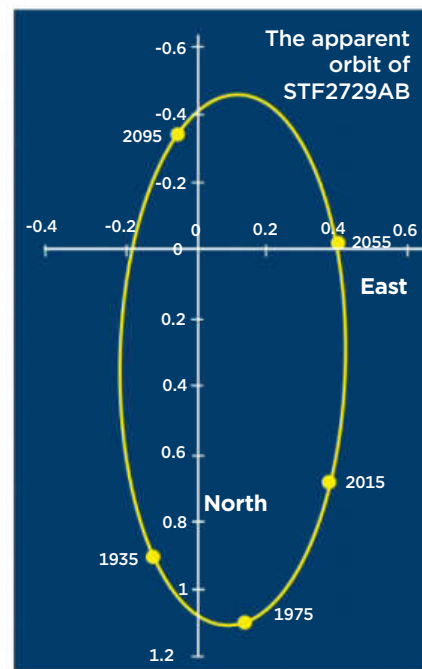
Starting at STF 2744, 2 degrees southeast from it is **STF 2755**, a wide and very unequal pair. The mustard-yellow 7th-magnitude primary has a quite-wide 10th-magnitude companion, seen in nice contrast with 65x through a 180-mm refractor.

From STF 2755, some 3 degrees south-southeast is **STF 2770**. My 235-mm SCT showed it well at 124x, the little 11th-magnitude companion in pleasing contrast with the bright and colourful orange-yellow primary. It should be accessible to a 100-mm refractor.

Just over 4 degrees southwest of Beta Aqr (mag 2.9) is **STF 2781**. Not a bright pair, the 8.7 and 8.9 mag stars are $2.7''$ apart. With my 140-mm refractor it was a quite attractive little double at 114x. Yellowish in colour, it sits in a low-



All of the stars covered in the text were found by F.G.W. (Wilhelm) Struve (1793-1864), the founder of modern double star work.



power field with patches of stars.

And to finish, a triple star. Some 2.5-degrees south and just west from Nu Aquarii (mag 4.5) is STF 2752. (Nu Aqr is also a guide to the striking Saturn Nebula, NGC 7009, about 1.3 degrees west of Nu.) **STF 2752 (AB)** is unequal, at magnitudes 7.3 and 10.0, and moderately close at $4.4''$. This deep yellow pair was easily seen at 98x through my 235-mm SCT. The much wider magnitude 11.6 companion (C), just north of west, was also easy - this is **BU 157**, discovered by Sherburne Wesley Burnham with a 150-mm refractor nearly 50 years after Wilhelm Struve found the closer pair.

Selected double stars in Aquarius

Star Name	R. A.	Dec.	Magnitudes	Separation	Position Angle	Date of Measure	Spectrum
4 Aqr (STF 2729)	20 ^h 51.4 ^m	-05° 38'	6.4, 7.4	0.8"	352°	2013	F5IV-V
STF 2744	21 ^h 03.1 ^m	+01° 32'	6.8, 7.3	1.3"	112°	2011	F7IV
12 Aqr (STF 2745)	21 ^h 04.1 ^m	-05° 49'	5.8, 7.5	2.5"	196°	2012	G4III
STF 2752	21 ^h 07.2 ^m	-13° 55'	AB 7.3, 10.0	4.4"	178°	2000	K1IV, M0
BU 157	"	"	AC 7.3, 11.6	26.5"	287°	2000	
STF 2755	21 ^h 07.5 ^m	-00° 10'	6.9, 9.9	25.1"	079°	2013	M3III
STF 2770	21 ^h 11.6 ^m	-03° 07'	7.6, 10.8	7.5"	247°	2009	K0III
STF 2768	21 ^h 12.0 ^m	-05° 49'	7.8, 10.5	7.9"	193°	2000	K3III
STF 2781	21 ^h 16.7 ^m	-07° 39'	8.7, 8.9	2.7"	172°	2007	F3V

Data from the Washington Double Star Catalog

In Struve's time, this star was beyond his 32" limit and to the east of the AB pair, not west of them as it is these days. It's a field star, and the rapid proper motion of the brighter pair has shifted C's relative position;

around 1939 it was only 3" from A, as Burnham had predicted from the proper motion. The AB pair is a binary, and a nearby object as the large proper motion suggests, only 57 light-years from us. ♦

Ross Gould has been a long-time observer from the suburban skies of Canberra. He can be reached at rgould1792@optusnet.com



Celestial Calendar

Catalina and Jacques

David Seargent

Two comets for early evening stargazers

At the time of writing, the most prominent comet in the skies during October will be C/2013 US10 (Catalina), as it drifts into the evening twilight on its way to perihelion (closest point to the Sun) at 0.82 a.u. on November 15. The comet will begin October moving slowly northward through Centaurus and will probably glow at around magnitude 8 or a little brighter if it holds to the trend followed earlier this year. It will continue to brighten slowly, reaching magnitude 7.5 or thereabouts by October 20, at which time it will cross into the constellation Hydra, very low in the evening twilight.

In the previous issue, mention was made of the new comet C/2015 F4 (Jacques), discovered on CCD images taken with the 0.28-m astrograph at the SONEAR Observatory in Brazil on March 27. On the assumption that this was a dynamically new comet, it was predicted to only reach around magnitude 12 at its brightest, at which time it would also be low in the northern skies for observers at mid-southern latitudes.

Further observations have, however, enabled the orbit to be refined and it now seems that this comet is a dynamically evolved one, returning on a moderately long period orbit of just under 1,300 years.

Although it is by no means a foregone conclusion, this might mean that this comet will become somewhat brighter than predicted as it nears the Sun and activates.

Perihelion occurred on August 10 at a distance of 1.64 a.u. and the comet will be located in Lyra as October begins. Although its magnitude is only predicted to be about 13 according to the initial brightness parameters, in view of the upgraded orbital information, it may do somewhat better than this, although it will be very low in the northern sky. ♦

David Seargent's latest book on comets, Snowballs in the Furnace, is available as a paperback-on-demand from Amazon.com



Comet C/2013 US10 (Catalina) will be low on the western horizon in the evening twilight. This view shows the sky from the latitude of Sydney at 7:55pm local time on October 20. The comet is not shown to scale; it'll be fainter and smaller. Image produced using Stellarium software.



Comet C/2015 F4 (Jacques) will be low on the northern horizon during early October. This view shows the sky from the latitude of Sydney at 8:00pm local time on October 10. The comet is not shown to scale. Image produced using Stellarium software.



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Why Pavonis?

This deep southern constellation hides a rich, red star

Alan Plummer

Well-placed for easy observing during October is the bright carbon star, Y Pavonis. Carbon stars are a class of evolved red giants, described more fully next month. With a visual range of 5th- to 7th-magnitude over a period of approximately 449 days, it is perfect for observation using 7×50 or 10×50 binoculars. Being a small-amplitude, long-period star, it needs observing only once per fortnight or so.

Some pointers on variable star observing with binoculars. First, avoid instruments with coloured objective lenses; many variables are quite red, and the apparent brightness may well be altered. And make sure you bring the target star and the comparison stars, each to the centre of the field of view, thus using the same part of your retina each time.

It's also always a good idea to make the line between the stars the same angle as the line between your eyes. You may have to contort your upper body to odd angles, but you'll avoid the third problem — position error — which is where there's a tendency to overestimate the brightness of one star that is below another.

Finally, a red star like Y Pav should never be stared at, but glimpsed quickly, in order to avoid the Purkinje effect — this is where a red light source, after



Y Pavonis is located at (J2000) 21h 24m 16.73s, -69° 44' 01.9". This chart is approximately 9 degrees across, and visual magnitudes are shown without decimal points (to avoid confusing them with very faint stars) — so 50 is 5.0 mag.

time, looks brighter than a white one.

This topic will be continued, with another target, in the next issue. ♦

Alan Plummer observes from the Blue Mountains west of Sydney, and can be contacted on alan.plummer@variablestarssouth.org

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Good things, small package

The shield of Scutum shelters a diverse collection of treasures

For a constellation you could hide with your hand held at arm's length, Scutum ('the Shield') parents an amazing wealth of deep sky wonders. Its favoured child is glorious Messier 11, whose magnificent rafts of pinpoint stars always deserve admiration. But Scutum's other celestial children are also noteworthy, so this month let's focus on some of them.

Only two objects from Charles Messier's famous 18th-century catalogue reside within Scutum, but that's the same number you'll find within Taurus. This seems impressive, considering Taurus is the 17th largest of the 88 constellations, while Scutum ranks 84th. Let's launch our tour with Scutum's often-neglected Messier object, **Messier 26**.

It's challenging to find star clusters amid the rich Milky Way star cloud that dominates Scutum, but Messier

26 is handily located 48' east-southeast of Delta (δ) Scuti. The cluster is easily visible through 15×45 image-stabilised binoculars in my moderately light-polluted sky. Its modestly large, hazy glow sports a lone star. Through my 130-mm refractor at 48×, M26 is an attractive gathering of 25 stars that spans about 10' and stands out well from its background. A magnification of 102× unveils about 40 stars. The western side of the group is sparsely populated, but a nice duo trims the west-southwestern edge.

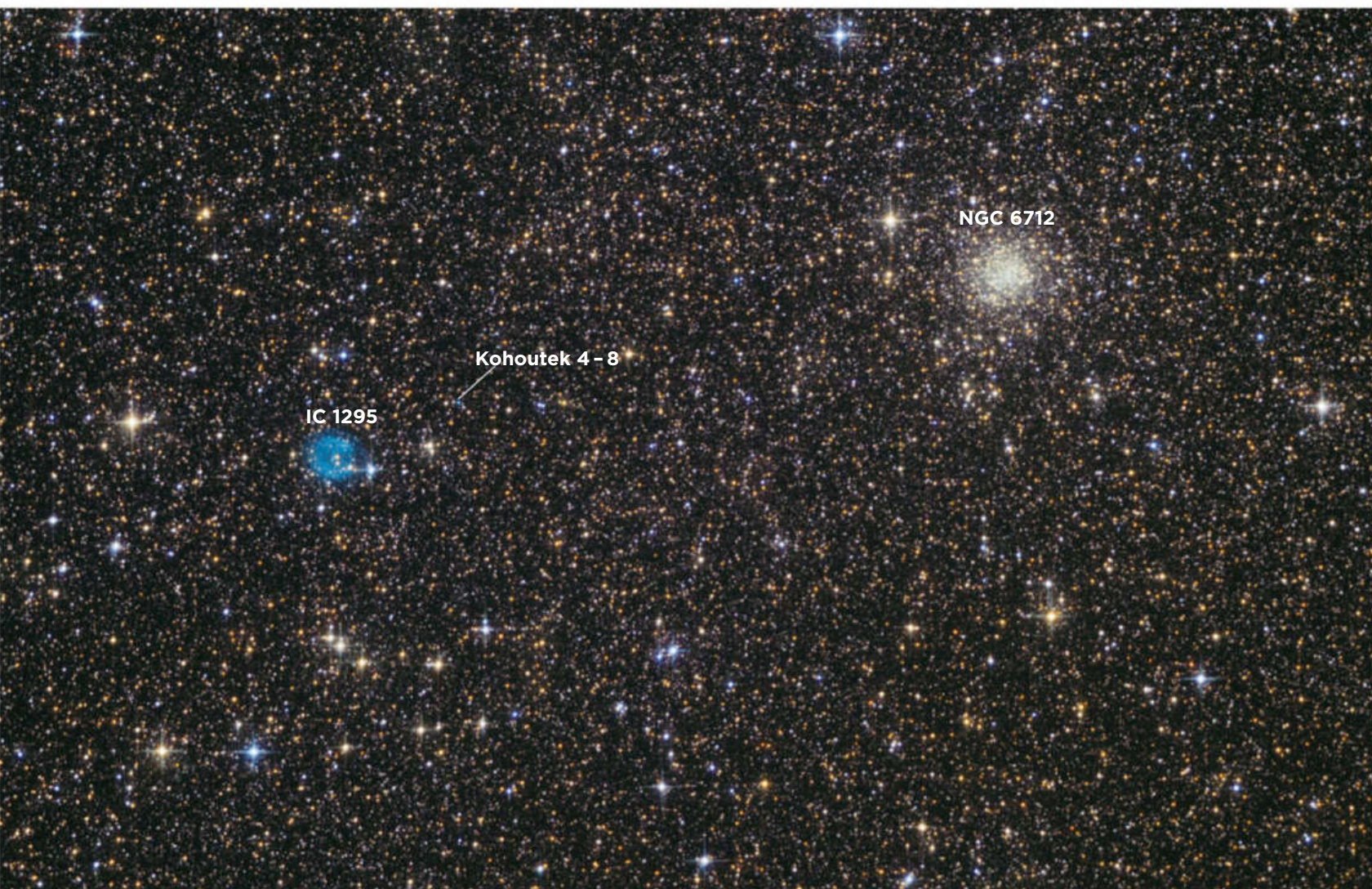
Amateur astronomer Mike Rowles and his family enjoy looking at M26 through his 25-cm reflector. He says it looks like a little jumping spider staring straight at them with its big, shiny eyes. I think that's a great description. Can you envision this cute celestial arachnid?

M26 is only 5,200 light-years away

from us, but it suffers considerable dimming from intervening dust in the plane of our galaxy. If we could sweep the dust away, M26 would shine at magnitude 6.2 rather than the 8.0 we see in our sky. It's also young as open clusters go, having celebrated its 85 millionth birthday.

Moving 2.0° east-northeast from M26 takes us to Scutum's only globular cluster, **NGC 6712**. Through 15×45 binoculars, it is a small, misty ball with a brighter heart and a faint star a little way off its east-northeastern edge. Through the 130-mm refractor at 23×, the cluster gleams as a granular haze and its attendant star becomes an orange ember. NGC 6712 is a lovely sight at 164×. Foreground stars are sprinkled over the cluster, but some very faint cluster stars, 13th-magnitude and dimmer, can also be seen. The cluster is quite pretty through my 25-cm





The cyan glint of planetary nebula Kohoutek 4-8 can be seen in a short arc of stars about 4.7° west-northwest of IC 1295.

SERGIO EGUIVAR

reflector at 213×; moderately faint to very faint stars are scattered across its entire face. The bright core is about 2' across and highlighted with two prominent stars in the southeast. A fairly bright fringe around the core spans 3' and hosts an eye-catching star in its east-northeastern side. The large, diaphanous halo gradually fades into the starry backdrop, and it's difficult to tell where it truly ends.

NGC 6712 and M26 fit within the same field of view through binoculars or a telescope at very low power. When viewed together, consider their differences. NGC 6712 is about four times as distant, 140 times as old, and holds roughly 700 times as many stars as M26.

Amateur astronomer Howard Lazerson told me about an interesting

asterism that he noticed with his 127-mm refractor and dubbed the **Bow and Arrow**. The Arrow is quite conspicuous through my 105-mm refractor at 17×. It's about 1° west-northwest of NGC 6712, 51' long, and flies northeast. Five stars in a 'V' form the arrowhead, the star at the end of the V's northwestern arm shining with a deep red-orange hue. This is the semi-regular variable star S Scuti, whose typical range is magnitude 6.6 to 7.3. The shaft of the Arrow has three stars. One additional star, the asterism's faintest at magnitude 9.0, joins shaft to arrowhead. Hanging 52' south of NGC 6712, the Bow is simply a gentle curve of three stars, magnitudes 5.8 to 7.0.

The large, low-surface-brightness planetary nebula **IC 1295** rests 24' east-southeast of NGC 6712. There's

// The large halo gradually fades into the starry backdrop, and it's difficult to tell where it truly ends. //

an 11th-magnitude star near its west-southwestern edge and an 8th-magnitude, yellow-orange star 7' to its east. I didn't see the nebula with my 130-mm refractor at 48× until I added an O III filter, and then a 1.5' glow popped into view. With the filter at 102×, IC 1295 looks slightly oval, tipped toward the nearby star, and it has a somewhat dimmer centre. At

this magnification, I can see the planetary without a filter. With an O III filter, my 25-cm reflector at 115× reveals some brighter patches along the nebula's rim. At 166× the nebula's rim is dimmer at the end facing the nearby star to its west, and there's a superimposed star west-southwest of the nebula's centre.

IC 1295 has a limb-brightened outer halo that spans $2.25' \times 2'$. Its surface brightness is only a magnitude or so fainter than the inner nebula. Although I couldn't see this with my 25-cm scope, German amateur Uwe Glahn's excellent sketch plainly shows that it's a viable target for large telescopes.

The material in the outer halo of IC 1295 and similar planetaries is thought to consist of material lost from an aging red giant star during an early phase of instability, while the central region is the result of the star's last gasp.

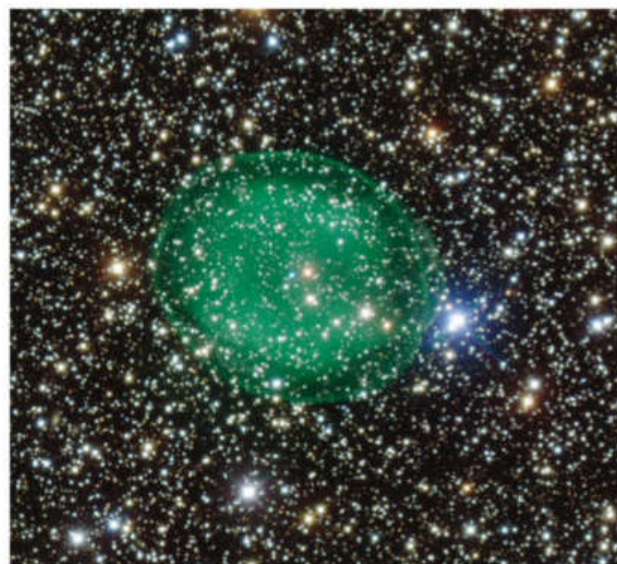
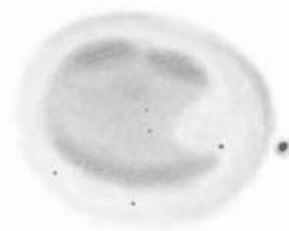
The starlike planetary nebula **Kohoutek 4-8** (PK 25-4.1 or PN G25.3-4.6) sits only $4.7'$ west-northwest of IC 1295. With my 25-cm scope at 213×, I see a $50''$ -long arc of three faint 'stars' at the nebula's location. My initial suspicion that that the middle one was the planetary was confirmed when I put an O III filter on the eyepiece. The western star disappeared, and the middle object then outshone the eastern star. Through my 38-cm reflector at 192×, the arc gains two more stars, but K 4-8 still claims the middle.

Hubble Space Telescope images show that the bright part of Kohoutek 4-8 has a barrel shape spanning roughly $0.7'' \times 0.5''$. There are also extremely faint, north-south ansae. According to a 2011 paper by Raghvendra Sahai and colleagues in the *Astronomical Journal*, K 4-8 is a young planetary nebula. Youthful planetaries are still small, perhaps a couple of tenths of a light-year across, a major factor in K 4-8's diminutive size in our sky.

The observations with the 130-mm refractor were made at one of my astronomy club's observing sites, whose sky is a fair bit darker than mine at home. When it clouded over that night, I packed up my equipment — so of course, the sky cleared again. I begged views through the 127-mm refractors of fellow club members Greg Nowell and Pete Fernandez for the remaining planetary nebula on my observing list, Minkowski 1-59 (PK 23-2.1 or PN G23.9-2.3). I've also observed it with 15-cm and 25-cm reflectors. Summing up our observations, I'd say that at magnifications of 200× or so, the nebula is a tiny, faint disk with averted vision but tends to look stellar with direct vision. An O III or narrowband filter may help.

Look for Minkowski 1-59 in a $19'$ -tall 'L' of stars that leans northeast. Delta Scuti marks the end of the L's base, and three evenly spaced stars (magnitudes 8.5 and 9.8) dominate

Uwe Glahn sketched IC 1295 as seen with his 68.5-cm Newtonian reflector at 293×.



This image of planetary nebula IC 1295 from the Very Large Telescope of the European Southern Observatory, shows a dying central star surrounded by a delicate green shell of nebulosity.

Spring sights in Scutum

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Messier 26	Open cluster	8.0	10'	18h 45.3m	-9° 23'
NGC 6712	Globular cluster	8.1	9.8'	18h 53.1m	-8° 42'
Bow	Asterism	5.1	50'	18h 52.5m	-9° 39'
Arrow	Asterism	5.3	51'	18h 49.9m	-8° 12'
IC 1295	Planetary nebula	12.5	$107'' \times 90''$	18h 54.6m	-8° 50'
Kohoutek 4-8	Planetary nebula	14.0	stellar	18h 54.3m	-8° 48'
Minkowski 1-59	Planetary nebula	12.5	5''	18h 43.3m	-9° 05'
NGC 6649	Open Cluster	8.9	6.0'	18h 33.5m	-10° 24'

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

the L's back. You'll find M 1-59 one quarter of the way from the back's middle star to its southwestern star.

Let's finish our tour with the diamond-dust cluster **NGC 6649**, located $41'$ northwest of the deep-yellow, 5.1-magnitude star HD 171391 (SAO 161632). Through my 130-mm refractor at 23×, the cluster's grainy haze is about $5'$ across, with a red-orange star at its south-southwestern edge. A magnification of 164× plucks 20 fairly faint to extremely faint stars out of the mist, but NGC 6649 teems with more than 470 stars. How many can your scope resolve? ♦

Sue French welcomes your comments at sfrench@nycap.rr.com.



Venus' unearthly glow

Modern research breathes new life into an enduring mystery.

For centuries, telescopic observers of Venus have occasionally reported an elusive, if not illusive, glow on the nightside of the planet. This 'ashen light', as it became known, resembles the faint Earthshine seen on the darkened portion of a nearly new Moon.

The literature on the subject is confusing. First, observations of the ashen light proper, in which the nightside appears brighter than the dark background sky, are often lumped with those where the nightside appears darker than the background sky. (The latter is a contrast effect.) Moreover, with an object as difficult to observe as Venus, illusions and optical effects abound: for instance, there is our well-known proclivity to 'connect the dots' into complete figures, as well as the scattering of light by optical systems. (Observations made with reflecting telescopes are especially suspect, because of diffraction by secondary-mirror supports.)

Nevertheless, a handful of observations cannot be so easily dismissed. Assuming that a real Venusian phenomenon might be involved, what can the physical explanation be?

In the case of the glowing dark side of the Moon, Earth's reflected sunlight is the explanation, as Leonardo da Vinci realised long ago. But Venus does not have a satellite, and while Earth would no doubt appear brilliant from Venus, its reflected light is far too feeble to produce such an effect. Many other explanations have been proposed over the years, some more ingenious than plausible — among them the notions that the inhabitants of Venus had set fires to clear forests or erected festival lights hailing new Venusian emperors!

Less far-fetched was an 1872 proposal by Pierre de Heen suggesting that, since Venus is much closer to the Sun, auroral activity there must have intensity 'the likes of which we can hardly imagine' and that this might account for the ashen light. His idea won support well into the 20th century, prompting Patrick Moore, in his 1956 classic *The Planet Venus*, to conclude that the hypothesis "seems to be the best explanation."

Credible witnesses

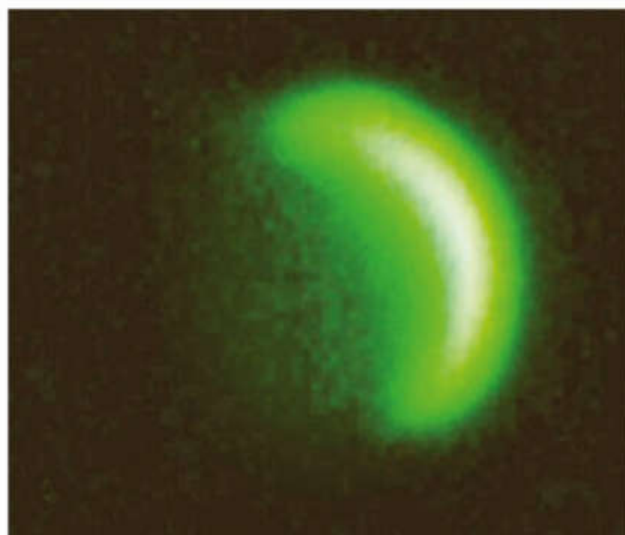
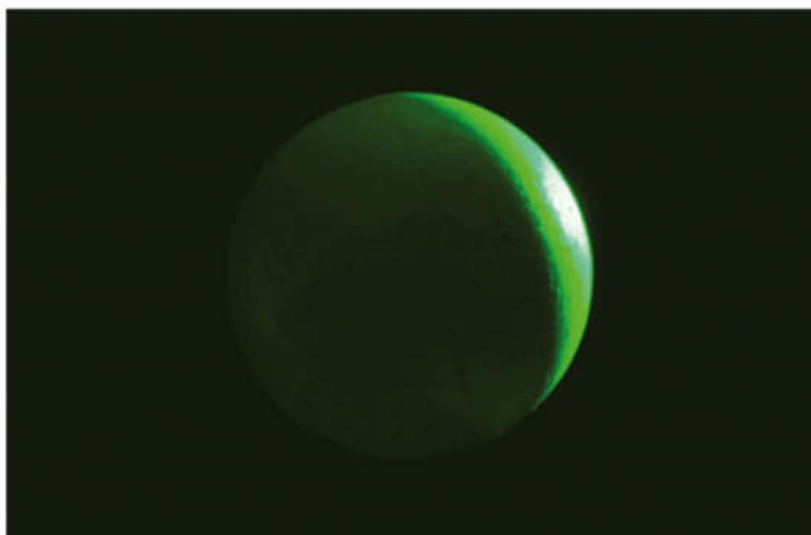
At about that time, high-school students Dale Cruikshank and Alan Binder were working as summer assistants at Yerkes Observatory in the USA. It was a dream job for anyone interested in the planets,

and they enjoyed the opportunity to observe with the great 40-inch refractor, sometimes at night but regularly during the daytime when it wasn't needed for other research. Then Mercury and Venus proved to be the most rewarding objects.

They often noticed tantalising surface detail on Mercury, as well as variable dusky bands on Venus, resembling those first photographed in the ultraviolet in 1927 by Frank Ross at Mount Wilson Observatory. The young students routinely observed Venus at 550× and 1200× through a Schott GG-14 yellow filter to reduce the telescope's stray (extra-focal) blue light.

On July 11, 1959, Cruikshank noted an unusual "halo" extending beyond the planet's cusps. This very faint glow remained visible even when the bright portion of Venus was occulted to reduce potential contrast effects. The glow was not detected the following two days, but on July 14 Cruikshank and Binder independently observed it. The glow remained sporadically visible on subsequent occasions.

Crucially, July 1959 was near sunspot maximum. Indeed, during the interval when they were seeing the glow around Venus's nightside,



In May 2012 the authors photographed a simulated Venus through a green filter (far left) to mimic how it should appear telescopically — and then photographed Venus itself with the same camera and filter using a 28-cm telescope. The resulting stack of three images (left) reveals a subtle glow on the planet's nightside — but it's an artifact due to light leakage in the filter and extreme contrast enhancement.



Left: This sketch by Dale Cruikshank shows how Venus looked during a daytime observation in 1962. Note the mottled glow on the planet's nightside.
Right: Astronauts aboard the International Space Station routinely see aurorae. Red emission typically occurs higher up than green emission.

a number of powerful solar flares had been reported. Cruikshank and Binder's plot of the timeline of the occurrences of the halo and the big solar flares showed what seemed to be a tantalising correspondence between the two.

Three years later, by then undergraduates, the two young observers followed their mentor, Gerard P. Kuiper, to the University of Arizona's new Lunar and Planetary Laboratory, where they wrote a brief paper titled 'Solar Activity and Observations of the Nocturnal Luminescence of Venus.' Kuiper suggested they withhold publication pending the results of sensitive spectrographic studies being planned by professional astronomers. Unfortunately, those studies yielded negative results, and a few months later NASA's Mariner 2 spacecraft discovered that, unlike Earth, Venus has no magnetic field. Since terrestrial aurorae are intimately tied to Earth's magnetic field, it no longer seemed plausible that the ashen light — whatever it was — could be an auroral phenomenon.

There were no further developments until late 1975, when the Soviet Union's Venera 9 spacecraft studied Venus from orbit and detected oxygen emission lines in its nightside atmosphere. The lines, which appeared in both the visible and near-infrared parts of the spectrum, were later found to vary in brightness and to respond to changes in solar activity. In 1992, Cruikshank, by then a professional astronomer in Hawai'i, remained convinced that "strong outbursts of oxygen emission intensity might explain the reliable visual reports of the ashen light," and he wrote a paper

encouraging amateurs to take up the quest with the high-quality equipment then becoming available.

Fast-forward to the CCD era, when confirmations of elusive phenomena such as the ashen light should have been forthcoming — were it real. But

no digital image has ever registered it convincingly. A dim infrared glow due to the planet's superhot surface has been recorded, but that's in a spectral region inaccessible to visual observers and thus can't be identified with the ashen light.



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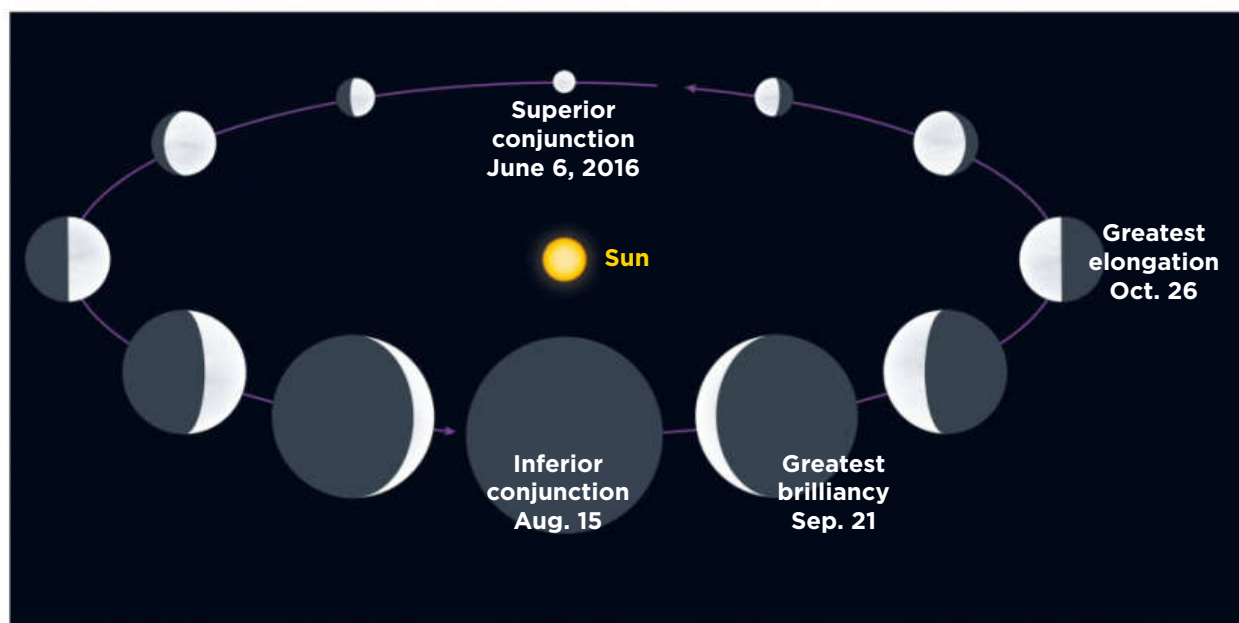
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Observers' next opportunity to search for Venus' ashen light comes in October, when Venus appears in the predawn sky after inferior conjunction.

S&T: LEAH TISCIONE



A solar-flare trigger?

In 2012, we made a series of observations of the nightside of Venus in the months before its transit across the Sun. We had serious gear — Celestron 28- and 35.5-cm Schmidt-Cassegrain telescopes and the 24-inch Clark refractor at Lowell Observatory — and we benefited from Cruikshank's advice and his narrow-bandpass filters. But we saw no hint of an ashen-like glow. Our disclaimer, however, is that during that time the Sun was fairly quiescent, with no strong flare activity — and this fact might be significant, in light of some suggestive recent research.

Working at Apache Point Observatory in New Mexico, astronomers Candace Gray and Nancy Chanover (New Mexico State University), Tom Slanger (SRI International) and Karan Molaverdikhani (University of Colorado) observed Venus spectrographically on four separate occasions between 2012 and 2014. Fortuitously, during each observing window an X-class solar flare — the strongest kind — was directed right at Venus. As Slanger reported at the 2014 meeting of the AAS's Division for Planetary Sciences in Tucson, "The results were amazing! There was a major solar storm in July 2012, producing an X-flare and huge coronal mass ejection that was directed right at Venus. We saw the brightest green line [of fluorescing oxygen atoms] that had ever been detected."

// Conceivably some kind of process involving the solar wind is triggering auroral glows. //

The green emission line wasn't detected after every flare but rather after only those that drove charged particles directly at Venus. While the planet lacks a global magnetic field, it does have an 'induced' field, produced when the Sun's magnetic field, embedded in the solar wind, becomes wrapped around the planet's ionosphere. There's also a long magnetotail extending out from the planet on the side opposite the Sun. So conceivably some kind of magnetic-reconnection process involving the solar wind is triggering auroral glows.

That's in keeping with results from ESA's Venus Express, which has shown that high-energy electrons are being channeled into the planet's nighttime atmosphere, where they excite oxygen atoms. Given the lack of a magnetic field, however, they're not channeled toward the poles (as occurs on Earth) but instead get dispersed. The result: aurorae at all latitudes.

Based on these and other spectrographic results, Gray posits that the brightness and intensity of

green-line emissions in the Venusian atmosphere likely depend on the strength of the solar flare, the depth in the planet's atmosphere at which the oxygen excitation occurs, and other as yet unknown factors.

Obviously there are chains of uncertainties here, but the auroral theory seems viable once again, providing a great opportunity for amateurs to take up the chase. If there are indeed Venusian auroras, can they be linked to solar X-flares and detected visually from Earth? If so, there might be something to the ashen light after all.

Like Cruikshank and Binder in 1959, persevering amateur observers armed with patience, attention to detail and today's excellent equipment — as well as some luck — should take advantage of the current year's apparition of Venus to look for any hint of ashen light. The planet's thin crescent should be optimally placed in the morning sky during October.

Since major solar flare activity is likely to continue during this window, this might be a golden opportunity to finally snare the 'Loch Ness of the solar system,' as the ashen light has been called. Will you be the one to do it? ♦

William Sheehan is a veteran Solar System observer, historian and author. An avid astro-photographer, Klaus Brasch took his first grainy Moon pictures in 1959 and now enjoys digital imaging from his backyard observatory.

The Moon meets Venus

Steve Kerr

A golden opportunity for hunters of the planet's 'ashen light'

Occultations are events which, with careful planning, give amateurs with ordinary scopes the chance to make extraordinary observations. This October, an occultation will give us an opportunity to hunt one of the most elusive mysteries of astronomy — the 'ashen light' on the unlit side of Venus, described in the article on the preceding pages.

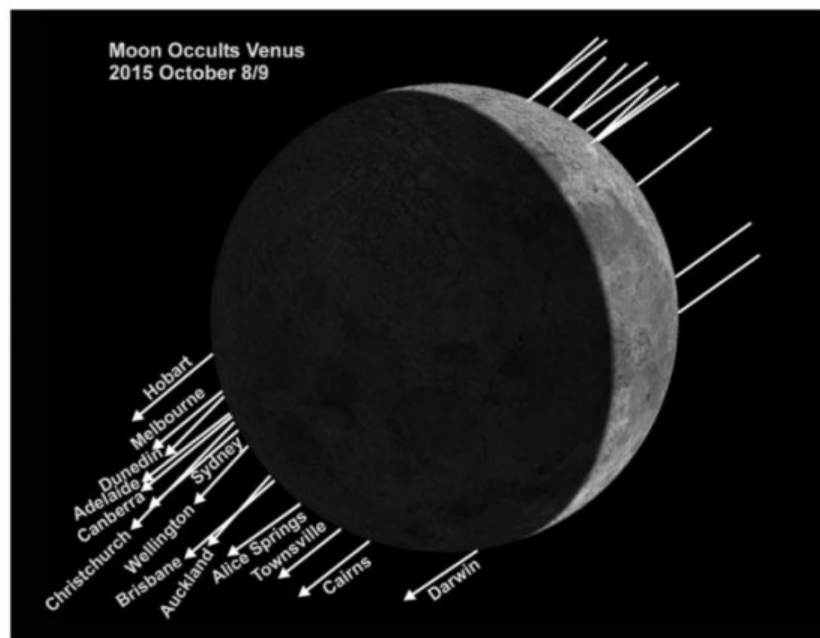
One of the major barriers to objectively observing Venus' unlit side is the overwhelming glare of the sunlit side. A lunar occultation — where the Moon passes in front of a planet — offers a chance to hide that glare and take a good look at the unlit side, albeit for only a brief period. On the morning of Friday, October 9, observers in Australia (except Western Australia) and across New Zealand will witness just such an event, as Venus slides behind the bright limb of the Moon before emerging from the unlit side.

Although the glare of the Moon and the fact that the unlit side of Venus disappears first makes the disappearance unsuitable for ashen light hunters, it will still be very spectacular, as Venus has a much higher surface brightness than the Moon. Looking at the Moon through a telescope, it can be difficult to remember that it has much the same colour and reflectivity as coal. But seeing it beside the much more reflective cloud cover of Venus, especially at high magnification, will accentuate the contrast.

Observers in the eastern states will see the disappearance with the Moon and Venus low in the eastern sky, with only Hobart suffering any significant amount of dawn twilight interference. For those in the south-eastern parts of South Australia, the event will be at unrealistically low altitudes; the Northern Territory will miss out on the disappearance as the Moon and Venus will not yet have risen, while New Zealand observers will see the entire event in bright daylight. If you're one of the latter, make absolutely sure that your telescope cannot be pointed accidentally at the Sun — setting up in the shadow of a solid building is one strategy to ensure this cannot happen.

For those chasing the ashen light, the

On the morning of October 9, observers in New Zealand and most Australian states will see the Moon move in front of Venus. When the planet reappears we'll see its unlit side first, providing a chance to search for the mysterious ashen light.



reappearance will be the event to watch. The best locations will be in South Australia and the Northern Territory, for there the reappearance will occur in a dark sky. Eastern state observers will see the reappearance either in very strong twilight or with the Sun just above the horizon; New Zealand

observers will still be in bright daylight. A bright sky may thwart ashen light observations.

Importantly for those seeking the ashen light, Venus will be a slight crescent. The unlit side of the planet will be the first to reappear, and this is when you'll have the chance to look for the mysterious glow before the sunlit side reappears. How long you'll have will depend on your location — perhaps as much as 30 seconds at Alice Springs and Adelaide, but as little as 15 seconds in Darwin. One of the biggest challenges is to know exactly where to look along the unlit edge of the Moon to catch Venus emerging. The diagram shows the apparent path of Venus behind the Moon's disk and the table gives the times of disappearance and reappearance for a range of places. For other locations, interpolate to estimate your own circumstances.

This occultation will offer a chance to take some spectacular images and to search for evidence of the ashen light. Images of the latter would, of course, be very scientifically valuable (for which information about the spectral response of the imaging system and any filters would be critical.) We'd love to hear how you fare with this spectacular event. ♦

Occultation of Venus by the Moon, October 9

Location	Disappearance	Reappearance
Adelaide	4:55 ACDT	6:08 ACDT
Alice Springs	-	4:45 ACST
Auckland	8:12 NZDT*	9:52 NZDT*
Brisbane	4:21 AEST	5:47 AEST*
Cairns	4:08 AEST	5:12 AEST
Canberra	5:32 AEDT	6:53 AEDT*
Christchurch	8:22 NZDT*	9:52 NZDT*
Dunedin	8:23 NZDT*	9:48 NZDT*
Hobart	5:49 AEDT	6:59 AEDT*
Melbourne	5:35 AEDT	6:49 AEDT*
Sydney	5:31 AEDT	6:54 AEDT*
Wellington	8:20 NZDT*	9:56 NZDT*

* Sun is above the horizon at the time of the event. NZDT, New Zealand Daylight Saving Time = UTC+13 hours; AEDT, Australian Eastern Daylight Saving Time = UTC+11; AEST, Australian Eastern Standard Time = UTC+10; ACDT, Australian Central Daylight Saving Time = UTC+10.5; ACST, Australian Central Standard Time = UTC+9.5.



Spring Stars

IN THE NEIGHBOURHOOD
Above: At 10,500 light-years
away, M22 is one of the
closest globular clusters to
Earth. ESA / HUBBLE & NASA

Seek out these targets
for small scopes
and binoculars in
October's evening sky.

I began stargazing by learning the constellations with my unaided eyes and 7×35 binoculars. My first 'serious' telescope was a 70-mm refractor, which I used primarily near my home in a densely populated city. So I've always had a soft spot for bright stars and star clusters, which look great through small instruments and don't suffer too much from light pollution.

As luck would have it, October's evening sky has many bright clusters that lie near prominent stars, making them especially easy to locate. Let's

start at 2.8-magnitude Lambda (λ) Sagittarii, also known as Kaus Borealis. Lambda isn't outstandingly bright, but it's instantly recognisable. Telescopes show that Lambda has an orange or reddish hue. It is, in fact, an orange-red (class K0 IV) subgiant, a star that's transformed most or all of the hydrogen in its core to helium.

Just 2½° northeast of Lambda, readily visible in the same binocular or finderscope field, is Messier 22, the third-brightest globular star cluster in the sky. Messier 22 ranks very high in the quality that makes globular



TONY FLANDERS

clusters so spectacular: the number of individual stars visible through a telescope. Amateur astronomers sometimes describe globulars as 'resolved to the core,' but we can only see the tip of the brightness pyramid; the overwhelming majority of any globular's stars are too faint to see even through the biggest backyard scopes. The closer the cluster, the more stars reach the visibility limit of any given telescope. M22 is the fourth-closest confirmed globular cluster, just 10,500 light-years from Earth, so it's one of the easiest globulars to resolve in small telescopes.

From my local city park, M22 stands out as a very bright fuzzball through my 70-mm refractor, and displays several pinprick stars over a bright haze through my 7-inch Dobsonian at 120×. (See my online Urban and Suburban Messier Guide at tonyflanders.wordpress.com for detailed observations of this and all other Messier objects from bright-sky sites.) Under dark skies, M22 is faintly visible to the unaided eye. It displays about a dozen individual stars through my 70-mm refractor at 60× and at least 100 stars through my 7-inch Dob at 120×.

While you're in the neighbourhood, take a look at Messier 28, which lies just 1° northwest of Lambda Sagittarii, making it even easier to locate than M22. M28 would be famous if it lay anywhere else in the sky, but it pales in comparison with M22. That's because it's 30% less luminous and 70% farther from Earth. M28 can be a little difficult to detect with small instruments under urban and suburban skies, but it forms a fine binocular field together with Lambda and M22 under dark skies. Through my 7-inch Dob, M28 appears quite bright regardless of light pollution, but I can only resolve a handful of its stars with that scope even under pristine dark skies.

The closest confirmed globular cluster is Messier 4, just 7,000 light-years from Earth. It's even easier to locate than M22 and M28, because it lies just 1.3° due west of Antares, the bright red star that marks the heart of Scorpius. But easy to locate and easy to see are two different things — it's very large and diffuse, with a low surface brightness (intensity) that can be swamped by light pollution. M4 is one of those paradoxical objects that's extremely prominent through small instruments under dark skies,

but notoriously challenging to novice stargazers in cities and bright suburbs even with the biggest telescopes.

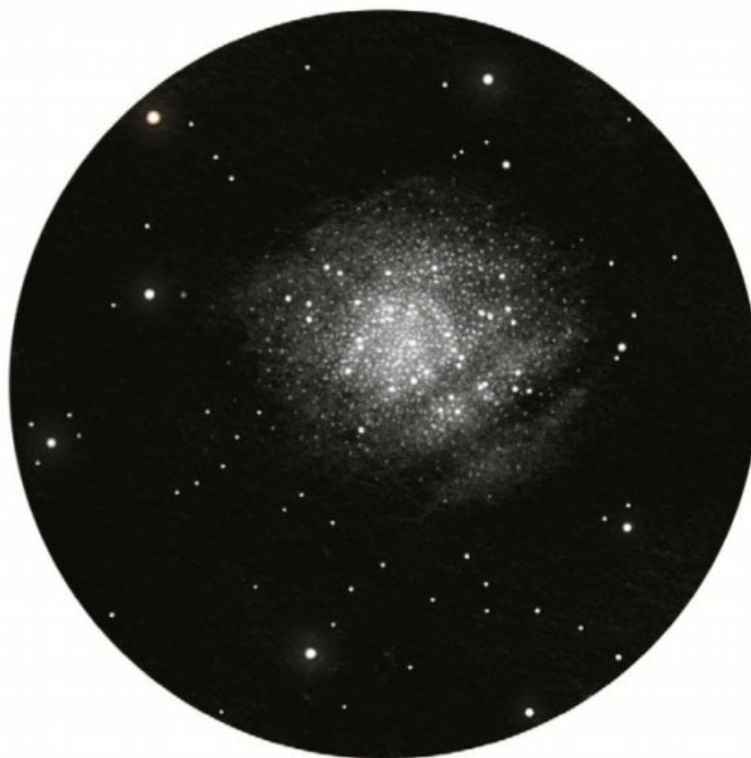
Like M22, M4 is extremely easy to resolve into individual stars. In fact, at 120× through my 7-inch Dob from my local city park, the brightest stars appear more prominent than the overall glow, an unusual situation for a globular cluster. This is the only globular cluster that Charles Messier was able to resolve; he described it as "a cluster of very small stars" rather than "a nebula without stars."

Antares, the signpost star for M4, is every bit as remarkable as the globular cluster. It's a red supergiant, one of the largest, most luminous, and coolest stars in the sky. It's almost 1 billion kilometres across, so big that if the Sun were at its centre, Mars and most main-belt asteroids would orbit inside it. Like most red supergiants, it's a semi-regular variable, ranging roughly from magnitude 0.9 to 1.1 over a period of a few years. It's also a notoriously challenging double star, with a 5.4-magnitude companion 2.9" from the primary. That would be an easy split for a small scope if both stars were equally bright, but the modestly bright companion is tough to tease out from the supergiant's glare.

Alpha Ophiuchi (Rasalhague) is

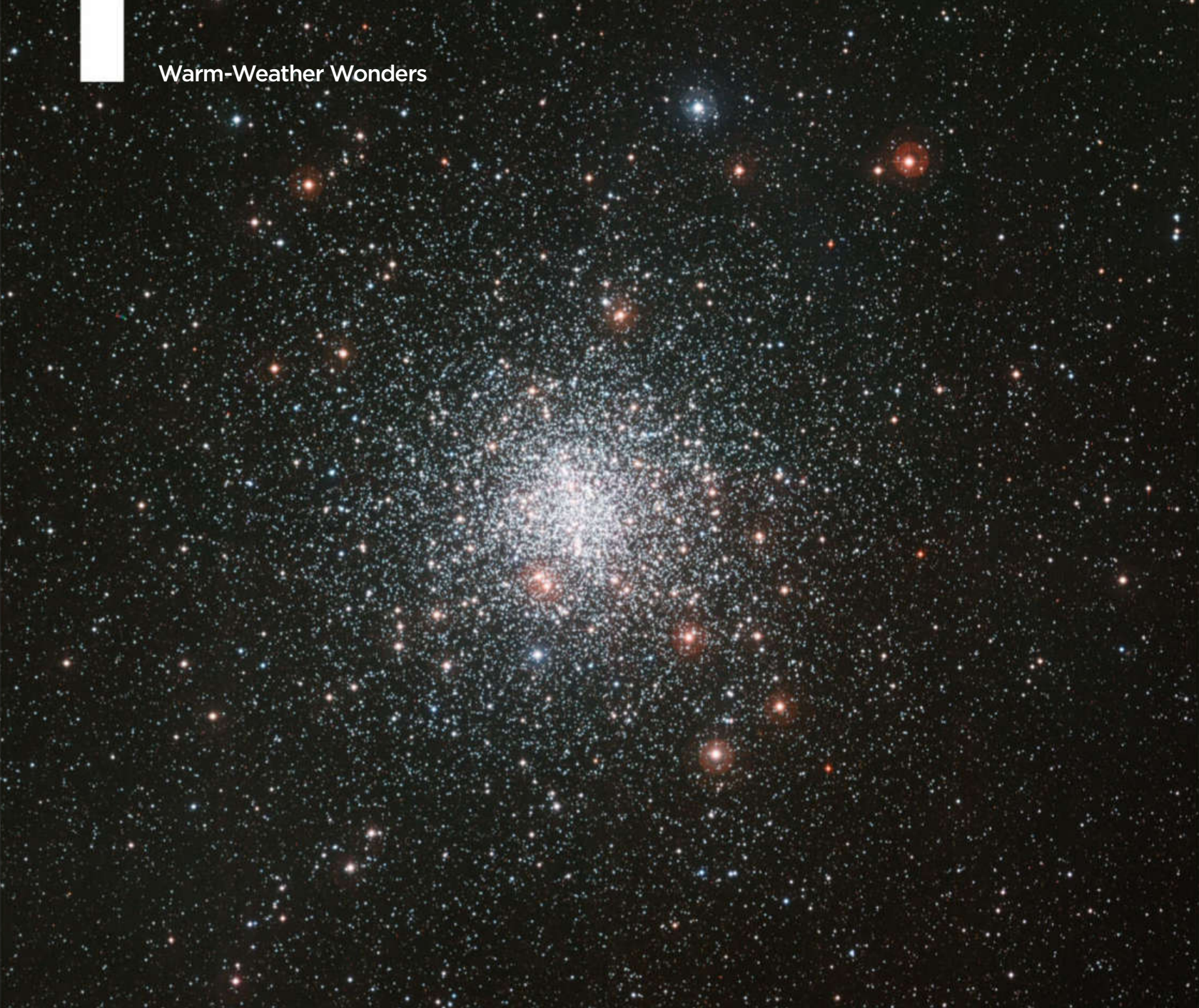
the brightest star in the huge chunk of sky that's bounded by Antares on the bottom, Vega on top, Altair on the left, and Arcturus on the right. Not knowing much about Rasalhague, I turned to my favourite resource, Jim Kaler's website at stars.astro.illinois.edu/sow/sowlist.html. Kaler, Professor Emeritus of Astronomy at the University of Illinois, is one of the world's leading experts on stars, and nobody writes on the subject with more clarity, authority, and passion. To Kaler, there are no boring stars; each one has its own unique personality. Kaler's website informed me that Rasalhague is a rather unusual class A5 giant. It has probably recently run out of hydrogen in its core, but is now powered by gravitational contraction, and unlike most giant stars, has not yet commenced fusing helium.

Beta (β) Ophiuchi, also called Cebalrai, lies 8° south-southeast of Rasalhague. It's a fairly typical orange-red (K2) giant, though Kaler notes that it exhibits strange pulsations over its 13-day period. Moving 1.4° northeast from Cebalrai you will find the open star cluster IC 4665, one of the sky's brightest and most attractive targets for small scopes and binoculars. It's a very young cluster, about 40 million years old, and dominated by about



FROM THE FUZZ
A small telescope resolves many of the stars of M22 to distinct points of light. This sketch represents the view seen with a 6-inch f/8 Newtonian at 120× magnification.

JEREMY PEREZ



ESO

The stars of spring

Object	Constellation	Type	Magnitude (v)	Size/Sep	RA	Dec.	Distance
Messier 22	Sgr	Globular cluster	5.2	24'	18 ^h 36.4 ^m	-23° 54'	10,500 l-y
Messier 28	Sgr	Globular cluster	6.9	11'	18 ^h 24.6 ^m	-24° 52'	18,000 l-y
Messier 4	Sco	Globular cluster	5.4	26'	16 ^h 23.6 ^m	-26° 32'	7,000 l-y
Antares	Sco	Double star	0.9-1.1, 5.4	2.9"	16 ^h 29.4 ^m	-26° 26'	550 l-y
IC 4665	Oph	Open cluster	4.2	70'	17 ^h 46.3 ^m	+5° 43'	1,400 l-y
Messier 71	Sge	Globular cluster	8.4	7.2'	19 ^h 53.8 ^m	+18° 47'	13,000 l-y
NGC 6544	Sgr	Globular cluster	7.5	8.9'	18 ^h 07.3 ^m	-25° 00'	10,000 l-y
NGC 6366	Oph	Globular cluster	9.5	8.3'	17 ^h 27.7 ^m	-5° 05'	11,500 l-y

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

a dozen very bright, blue stars. It can be resolved by small, hand-held binoculars and shines well even through heavy light pollution. With a telescope, use the lowest magnification available to frame this huge cluster.

My favourite stars in Ophiuchus are Delta (δ) and Epsilon (ϵ), also known as Yed Prior and Yed Posterior, respectively. Yed is Arabic for 'hand,' and these stars mark the western hand of Ophiuchus, the Serpent Bearer, where he grasps the neck of Serpens, the Serpent. Prior and Posterior indicate that Delta marches ahead of Epsilon in their slow nightly procession across the sky.

Delta and Epsilon shine at magnitudes 2.7 and 3.2, respectively, and they're just 1.4° apart, one of the closest and best-matched star pairs in the sky. I love star pairs because they're instantly recognisable regardless of their placement and orientation and

the level of light pollution. Whenever I see two 3rd-magnitude stars 1.4° apart in the spring sky, I know that they're the Yeds, just as I know that a golden 1st-magnitude star and somewhat fainter bluish star 4.5° apart in the summer or autumn sky are Castor and Pollux. The Yeds are particularly helpful in orientating me to the mass of medium-faint stars that form the huge, rambling constellation Ophiuchus.

Despite their proximity in the sky, Delta and Epsilon Ophiuchi are completely unrelated. They're both giants, classes M1 and G9, respectively, but Delta is more remote and much more luminous.

You may have noticed that most of the stars mentioned so far are either giants or supergiants. That's not entirely an accident. Although fewer than 1% of the Milky Way's stars are giants, and fewer than one



BLOOM OF YOUTH At 40 million years, expansive IC 4665 is one of the youngest open star clusters in the universe. POSS-II/STSC/Caltech / Palomar Observatory

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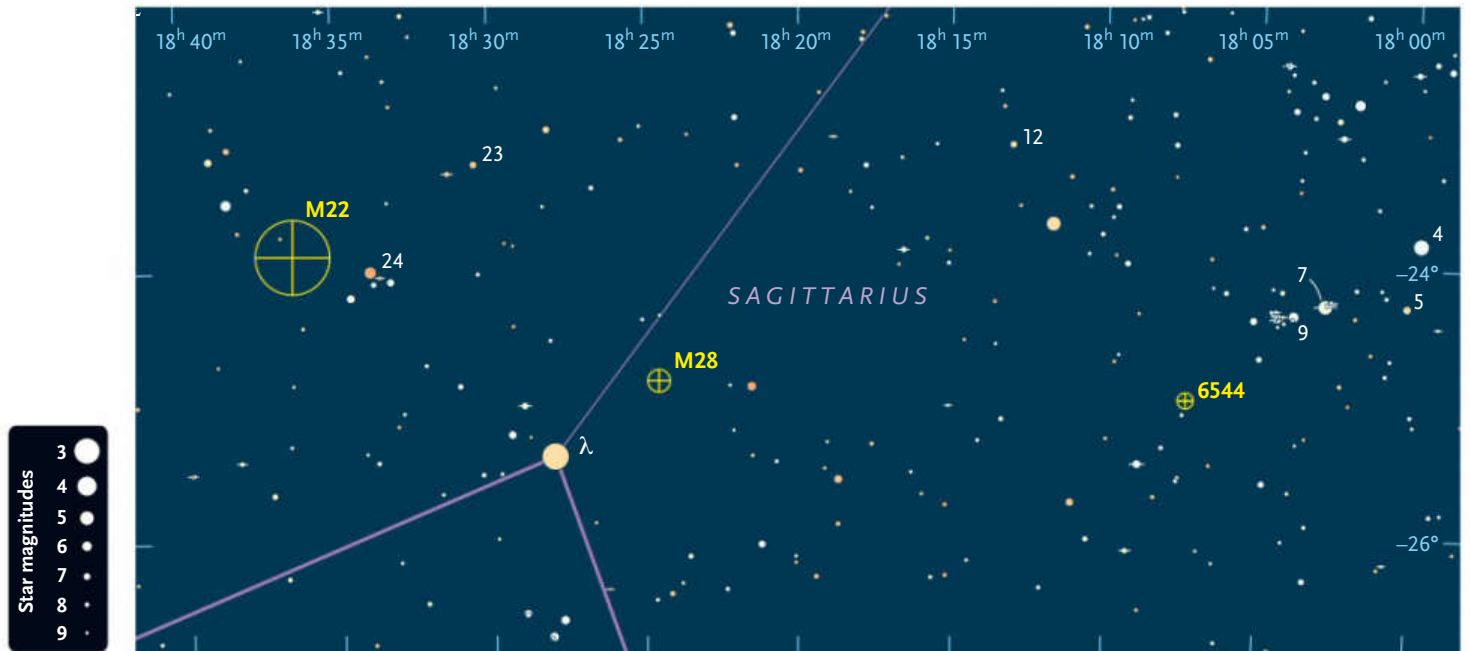


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STELLAR SPECTACLE Facing page:
This image from the Wide Field Imager attached to the MPG/ESO 2.2-meter telescope at ESO's La Silla Observatory shows the heart of Messier 4.

in a million are supergiants, these categories are represented disproportionately among the naked-eye stars because of their brilliance, which allows them to be visible from great distances.

October's evening skies are so full of showpieces that it's sometimes hard to choose among them. But the objects described here are so easy to locate that I pay each of them a quick visit almost every time I go out to view the spring sky. ♦

Contributing Editor *Tony Flanders* loves to view the deep sky from dark skies, from cities, and everything in between.

Other Nearby Globular Clusters

M4, M22, M10, and M12 are thought to be the first-, fourth-, tenth-, and twelfth-closest globular clusters, respectively. However, the precise order isn't clear. The far-southern globular NGC 6937 is listed as the second closest, but best estimates put it just 5% farther than M4, which is probably within the error of measurement. Also, some researchers think that there are one or two other, closer globular clusters (FSR 1767 and/or FSR 584) that are heavily obscured by interstellar dust and observable only in infrared, which penetrates dust clouds much better than does visible light.

As it happens, three of the other dozen closest are on good display in August's evening sky. The best and brightest of these is M71, eight-closest, which lies at the heart of the tiny constellation Sagitta. It's easy to resolve but very sparse for a

globular cluster. In fact, it was thought to be a rich open cluster for many decades.

The others are NGC 6544, third-closest, which lies 3.9° due west of M28, and NGC 6366, fifth-closest, 7.7° east of M10. Both of these are dimmed about 2½ magnitudes by interstellar dust, and NGC 6366 has the additional liability of being inherently faint and diffuse. But under dark skies both clusters are readily visible through a 15-cm scope and resolvable with a 30-cm.

That (including NGC 6937) accounts for eight of the twelve closest confirmed globular clusters. Two of the others are our magnificent far-southern objects NGC 6752 and 47 Tucanae. The remaining two, 2MASS-GC01 and GLIMPSE01, are dimmed more than 15 magnitudes by interstellar dust and observable only in infrared.



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An f/13 Holcomb reflector

A sturdy planetary Newtonian that uses a neglected mount design

When it comes to building telescopes, there are so many different approaches that it can take a while for an idea to resurface once it has fallen out of favour... such as the long-focus 20-cm Newtonian reflector built by Dunedin, New Zealand, telescope maker Vaughn Malkin (homepages.ihug.co.nz/~Svmalkin/home.htm).

Vaughn's scope bucks the current trend for fast and superfast primary mirrors with focal ratios of f/4 or less. To satisfy his planetary observing needs, he went all the way to f/13.

Apart from a generous image scale, a long-focus primary enables the use of a small secondary mirror to minimise diffraction effects that can mute low-contrast planetary details. Vaughn's scope is equipped with a secondary

only 32 mm across its minor axis, yet it still maintains a generous fully illuminated field. This size amounts to only a 16% obstruction — well under the 20% recommended for a planetary reflector.

With the optics sorted, the next challenge was to come up with a tube assembly rigid enough to hold the mirrors in perfect alignment. At 2.7-m long, Sonotube wasn't going to be the answer. After some hunting online, Vaughn secured a length of 20-cm-diameter unplasticised polyvinyl chloride (uPVC) tubing. Although more expensive than regular PVC, uPVC is more rigid. The piece was too short for the mirror's focal length, so he cut it in two and joined the sections with eight 20-mm-diameter aluminium poles clamped at each end with pillow blocks affixed to the uPVC pieces. The tube housing the primary mirror is 90 cm long; the upper section is about 157 cm.

The telescope's other striking feature is its Holcomb mount. This obscure design saw its heyday in the middle of the 19th century. "I stumbled across the Holcomb mount only after countless hours trawling the internet," Vaughn says. The website of telescope maker Mel Bartels (bbastrodesigns.com/HolcombeMount.html) provided the solution.

The mount was invented by America's first commercial telescope maker, Amasa Holcomb. And while it may look unusual, it's an elegant solution to the problem of pointing a telescope with a very long tube. How does it work? Think of a tripod in which one of the legs is the telescope itself with its back end resting on the ground. The scope is crudely aimed by picking up the front legs and pivoting the scope toward the region of sky you want to examine. Fine motion is facilitated by adjusting the lengths of the two front legs by means of two pulley systems — one for each leg. Adjusting both legs raises or lowers the front of the scope, while adjusting just



The altitude motion of the Holcomb mount is controlled by a pair of winch-and-pulley mechanisms that shorten or lengthen the assembly's two front legs. VAUGHN MALKIN

one causes the telescope to move diagonally, enabling objects in the eyepiece to be tracked. The legs attach to the telescope tube via a universal joint that permits a full range of motion. The Holcomb mount's chief limitation is that the scope can't reach the zenith or the horizon. Vaughn's instrument works over an elevation range of less than 26° to about 70°, which is well suited to planetary viewing.

Although it might appear ungainly, the Holcomb mount actually performs very well. "I guess all telescopes are compromises — here I'm sacrificing quick and easy access to the whole sky for fine control and stability over a much smaller region," Vaughn says. "For a visual planetary observer, it works great since there's no waiting for things to settle after you touch the focuser or adjust the aim."

This combination of a long-focus instrument equipped with a small secondary mirror and a sturdy mount yields excellent lunar and planetary views. "Jupiter shows tantalising hints of detail in the belts," Vaughn reports. "But the Moon was something else — a nice clean image with more detail than I could ever hope to draw." ♦

Read about Gary Seronik's own long-focus Newtonian at www.garyseronik.com



Although unusual in appearance, form follows function with this long-focus reflector built by Vaughn Malkin. The scope is ideally suited to provide detailed views of the Moon and planets. VAUGHN MALKIN

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Rokinon 16mm f/2.0 ED AS UMC CS

The Rokinon 16mm f/2.0 ED lens is a hidden gem among the crowded field of wide-angle APS-C lenses.

ALL PHOTOS ARE COURTESY OF THE AUTHOR.

Astrophotographers are always on the lookout for a new toy, particularly one that promises to expand the horizons of their hobby. For nightscape photographers, a big part of this quest is to find a good lens that can perform well under the stars while fitting into their budgets: quality camera lenses can often cost upwards of \$1,500 or more.

The Rokinon 16mm f/2.0 ED AS UMC CS lens is a wide-angle lens designed specifically for cropped sensor (APS-C format) DSLR cameras, and it promises to perform like a big-bucks lens for a small-bucks cost. This bargain-priced, manual-focus lens touts sharp stars across its entire $69.7^\circ \times 49.9^\circ$ field of view. It accepts 77-mm threaded filters.

Rokinon lenses are manufactured by Samyang in South Korea and sold under a variety of additional brand names, including Bower and Vivitar. The lens comes with a front

and rear dust cap, a petal-style lens hood and a cloth pouch. It's offered with mounting systems for most popular DSLR APS-C-sized cameras, including Canon EF-S, Nikon F, Pentax K and Sony Alpha. It's also available for mirrorless cameras, including Canon EF-M, Fujifilm X, Sony NEX, Samsung NX and Micro Four Thirds. The version I tested used the Canon EF lens mount.

This lens has 13 elements in 11 groups, with two aspherical elements and one extra-low-dispersion (ED) element to minimise chromatic aberration. Its UMC coatings also minimise ghosting and flare.

As a manual-focus lens, the Rokinon 16mm has no electronics or motors, so it won't work with some of your camera's automatic exposure settings, such as shutter priority or program mode.

Fortunately, this isn't a concern when photographing the night sky,

WHAT WE LIKE:

- Fast, f/2.0 focal ratio
- Excellent value

WHAT WE DON'T LIKE:

- Only APS-C coverage
- Uneven corner performance

since these functions generally do not work on the dim subjects of astronomy anyway: you'll mostly be using the bulb setting in M (manual) mode. If you do need to use some form of auto exposure to keep exposures consistent, in most cameras you can use the 'A' or 'Av' (aperture priority) mode in which the aperture is fixed and the shutter speed is varied based on the light in your scene.

The aperture ring also is manual, and you'll need to set it to your desired

focal ratio before an exposure. The lens has half-stop click detents, ranging from f/2 to f/16. For astrophotography, you'll probably never use this lens stopped down past f/5.6.

Also note that lens information, including focal length and aperture, are not recorded in the EXIF image metadata when using the Rokinon 16mm, so be sure to take notes while you are shooting with it.

Stellar performance

As most astro-imagers know, photographing star fields is an unforgiving test for any lens, and reveals almost any lens aberrations. While most lenses will record good images with daylight subjects, stars are point sources; they'll show every one of a lens' optical defects, particularly when you view the image at full resolution.

I tested the optical performance of the Rokinon 16mm f/2 lens at various apertures, from f/2 to f/5.6, on star fields in the Milky Way. I alternately placed the a bright star in the centre of the field and at each of the corners to check for reflections and other defects.

Like the majority of modern lenses, the focus travel range on the Rokinon 16mm allows it to move slightly beyond the infinity (∞) mark on its

I found the focus ring to be very smooth and easy to use; there's no play or backlash as is often the case with many inexpensive lenses.

printed scale. Users shouldn't assume that reaching the end of travel will naturally be at infinity focus, where stars would be sharpest. Live focus mode at full magnification in your DSLR should be used to establish critical focus, particularly when shooting at f/2. I found the focus ring to be very smooth and easy to use; there's no play or backlash as is often the case with many inexpensive lenses. To ensure focus wouldn't slip during the night I placed a small piece of tape on the focus ring to lock it in place, particularly since I intended to handle the camera multiple times throughout the night.

Wide open at f/2, the lens has remarkably good performance. Stellar images display a small amount of coma



The Rokinon 16mm f/2 ED is available in multiple configurations to fit a wide variety of camera bodies. Its compact design allows the use of Astronomik's clip-in filters for astrophotography.

and astigmatism in the frame's corners and some minor lateral chromatic aberration as well, but not as much as many wide-angle zoom lenses display when used at full aperture.

As a rectilinear lens design, the Rokinon 16mm attempts to keep straight lines in the scene also straight in the image. But it does suffer from some minor radial barrel distortion, causing straight lines to curve as they move away from the centre of the frame. In astrophotography, barrel and geometric distortions are unnoticeable in single frames and are often automatically dealt with when assembling mosaics in most panorama software.



The lens includes front and rear caps and a petal-style lens shade.

A bigger issue with a fast lens like this one is vignetting — noticeably darkened corners of an image compared with the centre of the frame. The Rokinin 16mm exhibits about one stop of vignetting when used wide open at $f/2$ but improves quickly when stopped down to $f/2.8$, and the effect is virtually undetectable by $f/5.6$. Flat-field calibration can remove this effect when shooting at $f/2$, and some software programs, including Adobe Photoshop's RAW converter, can also compensate for the effect.

When shooting constellations on a tracking mount, stopping down to $f/5.6$ is not a problem, but smaller apertures don't let in as many photons. You'll need to expose about eight times longer at $f/5.6$ to achieve the same signal-to-noise ratio as an image shot at $f/2.0$.

This quality-versus-speed dilemma is a trade-off with any lens: fast focal ratios produce higher signal with reduced image quality, while slow focal ratios generate superior optical performance at the cost of longer exposures. Which compromise is better depends on the situation. For example, a fast focal-ratio lens used wide open is best for meteor photography, because it will record fainter meteors. In fact, even exceptionally bright meteors appear notably less impressive when shooting at slow focal ratios. This is because aperture is an important factor in

meteor photography — you can't simply expose longer for an object that is gone in a second or two. Likewise, great comets and bright aurorae will photograph better at $f/2$: you'll get more of the comet's faint tail in a short exposure and keep its nucleus from trailing, particularly in untracked exposures, when compared with slower lenses. And rapidly changing aurorae also require short exposures to avoid blurring.

Time-lapse nightscapes on a fixed tripod or a moving track will also benefit from the Rokinin's fast $f/2$ focal ratio — you'll record the star clouds and dust lanes of the Milky Way in shorter exposures, as well as some large, faint nebulae, particularly if you're shooting with a modified camera.

Optical alignment

One issue with inexpensive lenses you should watch out for is the misalignment of one or more optical elements. Misalignment reveals itself as asymmetrical coma around the stars throughout the field. I tested two samples of the Rokinin lens, and both were very similar, though neither was perfect. It's hard to say if this sample-to-sample variation is representative of the model.

While my testing revealed some asymmetrical coma, I still judge the performance to be very good. I've seen similar results in top-of-the-line

lenses that cost many times more than the Rokinin, and these minor distortions quickly disappear when stopping down the lens (see the test strips below).

Imaging with filters

Since I live far from truly dark skies, I often use a clip-in light-pollution filter sold by Astronomik (astronomik.com) that installs inside the camera body behind the lens, just in front of my Canon DSLR's mirror box. While clip-in filters won't work with certain lenses that extend too far into the camera body, my Astronomik CLS-CCD clip-in filter worked well with the lens, even at $f/2$. But the combination did produce slightly increased optical aberrations in the frame's corners. Stars became radially elongated away from the centre of the frame, and the filter also introduced lateral chromatic aberration, with the stars splitting into three non-overlapping red, green and blue images. Note that these effects are caused by the filter and are not a fault of the lens itself. Again, post-processing software can greatly mitigate these issues.

Star images recorded with the lens and a Canon T5i DSLR exhibit minor asymmetrical coma around stars across the entire field, which is reduced when you stop the lens down. The top strip displays stars in the centre of the frame shot at $f/2$, $f/2.8$, $f/4$ and $f/5.6$. The second strip shows the stars at the extreme top-left corner of the same frames.





Top: In practice, the lens produces excellent images when shot wide-open under a dark sky. This image taken at f/2 shows round stars nearly to the extreme corners. Total exposure was 116 minutes (232 × 30 seconds) with a modified Canon T3i at ISO 1600. **Below:** The author used the lens to shoot this image of himself during a night of imaging.

The bottom line

The Rokinon 16mm f/2.0 ED AS UMC CS lens is an excellent wide-angle lens for astrophotography. Its price, mechanical quality, smooth manual focus and impressive optical performance, even wide open at f/2, make it a very attractive lens. The fact that it is completely manual is no drawback at all for aurorae photography and astrophotography.

I highly recommend this lens for astrophotography, particularly for specialised subjects such as meteor showers, bright comets, aurorae and time-lapse starscapes. Stopped down it has excellent performance for wide-angle nightscapes as well as constellation and general Milky Way photography. ♦

Photographer *Jerry Lodriguss* blogs about his experiences at astropix.com





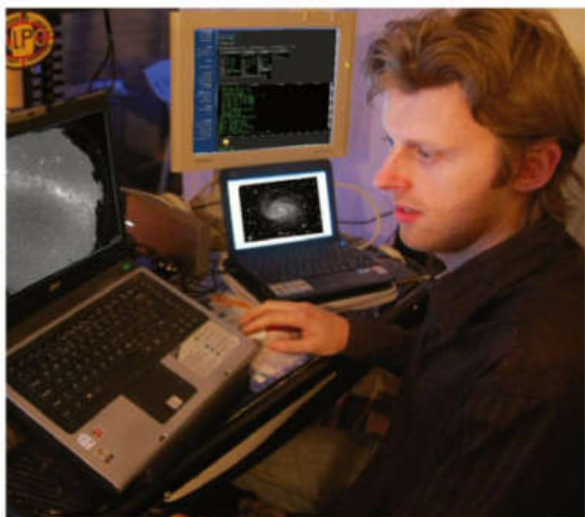
DAMIAN PEACH

Armchair Imaging

In the digital age, you don't need your own telescope to take stunning astrophotos



VIRTUAL DARK SKIES Facilities like the LightBuckets Dome in southern France offer amateurs access to dark-sky conditions that would otherwise require hours of travel or more to reach. *Below:* Author Damian Peach monitors conditions in Australia while imaging from half a world away. DAMIAN PEACH



The internet age has brought about many radical changes to our hobby, not least to astrophotography. Yet while the advent of large-format CCD detectors has revolutionised both amateur and professional imaging techniques, a second revolution has been occurring in recent years that has totally changed the game for imagers. That is the rapidly expanding access to high-speed internet, which has made it possible to use high-end telescopes in remote locations worldwide.

These days it's not necessary to drive to remote dark-sky sites to take deep, colourful astrophotos. In fact, owning a telescope of your own is no longer a requirement to produce jaw-dropping images. Renting time on remote telescopes via the internet has become an increasingly popular way for both amateur and professional astronomers to conduct observations.

Location, location, location

Imaging with telescopes thousands of kilometres away is quickly becoming commonplace. Several entrepreneurial companies have established 'telescope farms' that provide access to sky conditions far superior to what most of us encounter in our own backyards — and at a reasonable cost.

Currently three businesses offer completely independent time on their instruments to provide raw, uncalibrated data: iTelescope (itelescope.net), LightBuckets (lightbuckets.com), and the Sierra Stars Observatory Network (sierrastars.com). Their facilities are located under some of the darkest skies in the US, including in New Mexico, Arizona, and California. Additional facilities are open in Siding Spring Observatory in



DRONE SCOPES Using rental telescopes such as the iTelescope observatory at Siding Spring Observatory, Australia, anyone can take gorgeous images of galaxies, star clusters or comets from the comfort of home.

Australia and Europe. Spreading the facilities out worldwide in various longitudes offers users a good chance that an instrument will be available at any given time.

Rental telescopes vary greatly in aperture, focal ratio and detector size, with each setup specialised toward specific tasks. For example, small fast astrographs such as the popular Takahashi FSQ-106, coupled with large-format CCD cameras, are best suited to capturing expansive vistas several degrees across. These are ideal for shooting large nebulous regions within the Milky Way, open clusters, or the rare bright comet. On the other end of the range are large-aperture instruments geared toward shooting faint galaxies or planetary nebulae, or doing variable-star photometry. Currently there are no telescopes dedicated to planetary imaging, though I'm sure this will eventually change.

As should be expected, each instrument rides atop the best robotic mounts, which offer extremely accurate pointing and tracking. Additionally, most are equipped with a wide range of filters from broadband red, green, and blue to specialised narrowband and photometric filter sets. Some smaller

telescopes offer one-shot-colour cameras that are great for beginners and deliver surprisingly good results.

Because these services cater to different levels of interest and experience, it's important to understand how to use the equipment to get the most out of it. Most rental facilities available to amateurs are interfaced using ACP (Astronomer's Control Panel) by DC-3 Dreams, which was detailed in the July issue, page 66.

To help beginners get comfortable with using remote systems, most providers offer a free trial that lets you use one of the smaller telescopes to take an image. This is a great way to experience firsthand how the service operates without making a major commitment. After that, the hourly rates are very reasonable, especially when you consider the cost of setting up and operating a remote observatory yourself.

It's all in the planning

To get started, check the services provided by each facility and find the one that best fits your interests. Then create a user account with the provider through its website. Once registered you're ready to book your time. Costs vary depending on the

telescope — larger scopes are costlier to operate than smaller ones — and the length of exposure you desire. With some providers the cost is also affected by your membership level.

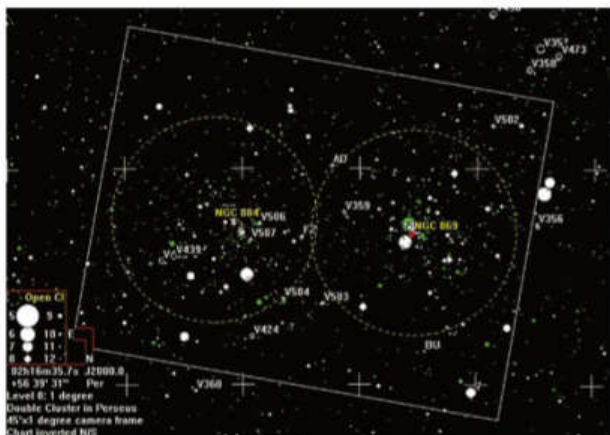
Before simply diving in and taking images, however, it's important to plan ahead so that you aren't wasting precious time and money haphazardly shooting targets. A critical piece of equipment you'll need in addition to your processing software to get the most out of your rental experience is an advanced desktop sky simulator. Software such as TheSkyX (bisque.com) or Guide 9.0 (projectpluto.com) permits you to input all of the relevant information that the remote facility provides on the imaging system you choose, including the detector size, telescope focal length, and camera position angle. You can then use these specifications to precisely plan your composition and take the best photo within your means. The more options available to you, the better your images can potentially be.

Planetarium software is especially vital for planning compositions involving multiple targets, which you can strategically position in the field of view to help balance your composition. Additionally, moving

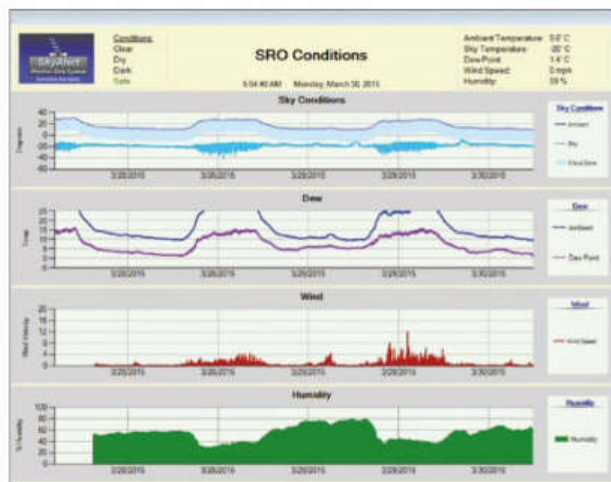
DAMIAN PEACH



VIRTUAL OBSERVING Taking advantage of online telescope services, author Damian Peach captured Comet Oukaimeden (C/2013 V5) as it passed by the colourful Rosette Nebula in Monoceros on the morning of August 24, 2014, without leaving his home in Southampton, England.



PLAN AHEAD Get the most out of your imaging time by planning your compositions using an advanced planetarium program such as *Guide 9.0* (above). This is particularly important when targeting moving objects such as comets and asteroids.



WEATHER MONITOR Each online service offers extensive weather monitoring services.

targets such as asteroids and comets require exact position info, and you want to be sure your exposures are short to keep their movement from compromising your image.

Once your planning is complete, you're ready to book your shots. Many users reserve time slots weeks in advance, so the most popular telescopes can become quite heavily booked around new moon. Reservation schedules on all telescopes are listed in local time at the observatory, so you'll need to convert this to your local time if you want to control the equipment manually during your reservation time.

I've come to appreciate what a tremendously powerful resource these rental facilities are. No longer are truly dark skies reserved for those lucky enough to live at favourable locations far from city lights.

Once you've logged in, you're greeted with the main overview page of the network. This displays a wide variety of information such as a world day/night map, telescope rental rates and what instruments are available for use. Live all-sky cameras and remote weather stations monitor conditions at each location. If adverse weather occurs, you will immediately be alerted. Aborted sessions can occur for a variety of reasons, not just cloudiness. High winds or very high humidity can, for instance, result in the observatory closing.

Scheduling an imaging run is almost just like using your own equipment at home. Exposure length, filter sequence, binning mode and choosing a star to auto-guide exposures on can all be customised to your preference. You can also request a live preview JPEG of each exposure as it's completed. This is always helpful as it lets you can check that the images are being captured as planned. Imaging runs can be aborted at any time for any reason.

Most facilities using ACP provide a live script from the telescope that tells you exactly what the telescope is doing in real time. Before capturing begins, the telescope will slew to a nearby star and perform a focus routine. This typically takes around 2 to 3 minutes. Occasionally the process will fail, and the telescope will default to using pre-defined filter offsets. While these settings are usually adequate, you can abort the run at any time if you are not happy and want to try again. You aren't charged for routine actions such as focusing or autoguiding calibration; you only pay for time actually collecting data.

Most telescope systems also 'plate solve' the images recorded. This means the operating software matches



EASY BOOKING Setting up your exposures through iTelescope.net is easy and intuitive. Note the extensive list of options. **Left:** Remote observing facilities permit users to shoot with the scope of their dreams. This image of M20, the Trifid Nebula, was captured from the iTelescope facility at Siding Spring Observatory in Australia, using a 68.5-cm PlaneWave CDK700 and FLI PL16803 CCD camera. Total exposure was 1 hour through colour filters. DAMIAN PEACH

the star field in the image to an extensive database to ensure the system is pointed precisely where you designated. All rental facilities' pointing is extremely accurate, so if you planned the observations well, your images should look exactly as envisioned.

Once the run completes, the system will automatically log you off the telescope and begin transferring your images to a private FTP user account. You can download these via an FTP client or through a web interface. Regardless of the telescope, data captured during any run is saved in the 16-bit FITS format, which is compatible with any software used for processing astronomical CCD images. Calibration images — dark frames, bias and flat-field images — are also provided, as well as fully calibrated images that have been automatically dark- and flat-corrected.

Once you have your data, you can

process your image like any other astrophoto.

Cost and benefits

Having been a dedicated amateur for more than 20 years, I initially felt odd being detached from the experience of being out there under the night sky with the equipment while recording my images. However, I've come to appreciate what a tremendously powerful resource these rental facilities are. No longer are truly dark skies reserved for those lucky enough to live at favourable locations far from city lights.

But, of course, this comes at a price. The longer you plan to expose to produce an image, the greater your expense will be. This is still comparatively cheap compared to the cost of purchasing a similar setup of your own. Even a modest robotic observatory can be rather expensive to assemble and operate, and it is never truly autonomous; even private

remote observatories require support staff to handle problems and routine maintenance.

Remote astronomy has rekindled my own interest in deep sky astrophotography and comet imaging. It also represents a better value when spending my money on astronomy. I enjoy actually making these observations, rather than investing in a system located under a mediocre-quality sky that can sit idle for weeks and months at a time. Renting remote systems enables you to make very high-quality observations so your money is spent in actually doing astronomy rather than on equipment. This also means you no longer need to be a seasoned imager to produce astrophotos that you'll be proud to show your friends and family. ♦

Best known for his world-class planetary images, *Damian Peach* often images comets and other deep sky objects using rental observatories worldwide.

Remote Imaging Facilities

Service provider	Telescopes	Apertures (cm)	Sites	Initial	Hourly cost	Website rate
iTelescope.net	19	9 - 68.5	USA, Spain, Australia	free	~\$45	itelescope.net
LightBuckets	5	11 - 84	France	free	~\$100	lightbuckets.com
Sierra Stars Obs. Network	5	37 - 81	USA, Australia	~\$65	~\$65	sierrastars.com



Under the Milky Way

BY BOLI

Astronomers gathered under the dark skies of western Victoria for the Snake Valley Astro Camp.

Dark sky stargazing doesn't get much better than this.

DANIEL GARNIERI

Some people get into astronomy due to a love of the scientific nature of the pursuit; others want to take pretty pictures, knowing that what we are witnessing now happened tens of thousands if not millions of years ago. Then there are those who simply want to stare through an eyepiece and marvel at the wonders of the universe and contemplate our place in it. One common element that unites us all is our enjoyment of fellow astronomers' company and the sharing of knowledge. We may be teachers, engineers or accountants by day, but we are all equal under the stars at night.

For anyone who wants to dip their toes into this fascinating (and at times expensive) hobby, the first piece of advice is almost always to attend a star party. Star parties are a great way to meet fellow astronomers and examine up close and personal the various telescopes, mounts and cameras advertised in magazines and websites. It's also a forum for information exchange, for learning tips and admiring the ingenuity of others with their DIY solutions.

One such star party is the Snake Valley Astro Camp, which has been running since 2005. The most recent event was held in late March, and saw dozens of astronomers descend on the sleepy town of Snake Valley in western Victoria, about thirty kilometres from the historic city of Ballarat. The Camp, which has a loyal following among

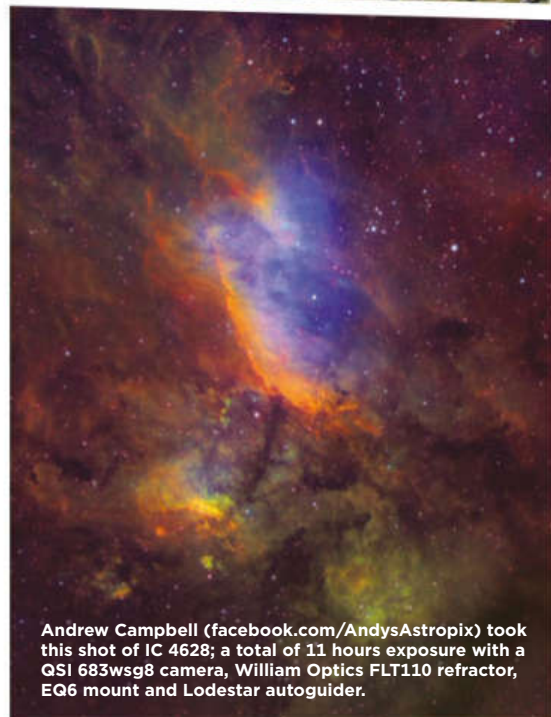
Victorian and interstate astronomers, was held in the informal and relaxed setting of Crystal Lake Cabins, a powered camping site with excellent facilities and, most importantly, dark skies.

On the first day of the event, stargazers arrived from mid-morning onwards to pitch their tents and unpack their gear. The site was divided into three sections: accommodation/amenities, astrophotography, and observation only. As the Sun went down and the stars began to shine, the Milky Way shone gloriously overhead, accompanied by the Small and Large Magellanic Clouds. But there was little time for dallying by the astrophotographers, as they began their alignment and calibration routines. In the observational section, things were much more relaxed as the whirling sounds of servo motors signaled the pointing of scopes in different directions.

As the temperature started to fall, excitement began to build as data started to appear on screens (along with frustration for those who received error messages). Between the wows and oohs and aahs, people chatted with their neighbours and started to forge new friendships. By about 3:00am, half of the group decided it call it a night



The obligatory group photo. The clarity of the Snake Valley sky is apparent even during the day. DANIEL GARNIERI



Andrew Campbell (facebook.com/AndysAstropix) took this shot of IC 4628; a total of 11 hours exposure with a QSI 683wsg8 camera, William Optics FLT110 refractor, EQ6 mount and Lodestar autoguider.

Astro Calendar

StarFest 2015

October 2-4

Held at Coonabarabran, home to Siding Spring Observatory, there'll be three days of activities during the Festival of the Stars
starfest.org.au

Siding Spring Open Day 2015

October 3

Australia's largest optical observatory throws open its doors to the public
starfest.org.au

Border Stargaze

October 8-11

Amateur astronomy star party near Albury on the NSW-Vic border
asaw.org.au/bsg

Snake Valley Astro Camp

November 6-8

Snake Valley, Vic
Phone: 03 5231 3048

VicSouth Desert Spring Star Party

November 6-9

Annual star party hosted by the astro societies of Victoria and South Australia
vicsouth.info

National Australian Convention of Amateur Astronomers

March 25-28, 2016

Held every second year, the NACAA is Australia's premier get together for amateur astronomers to discuss research projects and the latest technologies. In 2016 it will be hosted by the Sutherland Astronomical Society in Sydney.
nacaa.org.au

Royal Astronomical Society of NZ Conference

May 2016

Annual meeting of New Zealand's astronomers
hbastrosoc.org.nz/rasnz-conference-2016/

South Pacific Star Party

May 5-8

Annual star party hosted by the Astronomical Society of NSW
asnsw.com/spsp

WHAT'S GOING ON?

Do you have an event or activity coming up?
Email us at editor@skyandtelescope.com.au.



IC 2944, also known as the Running Chicken Nebula.

PHOTO BY NEALE WALTERS.

and snuggled up in their beds or sleeping bags.

Day two started to the sound of galahs and cockatoos. Any lack of sleep was quickly forgotten as discussion turned to equipment and processing techniques. Some also got their first views of the Sun through dedicated solar scopes. Before long, day rolled into evening yet again, and another night of cloudless skies appeared. A small group of stargazers lined up in the observation field and admired some breathtaking views of deep sky objects through equally breathtaking SDM telescopes. It was an unforgettable

experience, one you simply cannot have in light-polluted cities.

For some, Monday's work commitments meant they had to pack up on Sunday and drive home, but not before the obligatory group photo and a promise to return for the next Astro Camp. For those who could stay for the third night, unfortunately the luck with the weather did not hold — but the time was usefully employed on image processing (plus some much needed sleep) before the pack up and the drive back home.

The next Snake Valley Astro Camp is scheduled for November 6-8, 2015. ♦

10 & 5 Years Ago



October 2005 Are we alone?

Frankly, there's precious little reason to believe that sophisticated alien life is either already here on Earth or planning to come soon. But a radio signal, or a flashing beacon of light — possibly sent many hundreds or thousands of years ago — could be washing over our planet now. That is the premise of SETI (the Search for

Extraterrestrial Intelligence), a carefully constructed experiment designed to hunt for deliberate hailing signals that would betray the distant presence of aliens clever enough to assemble a transmitter or laser.



October 2010 Hubble's 20th birthday

From its perch 560 kilometres above Earth, the Hubble Space Telescope has seen farther and sharper than any optical/ultraviolet/near-infrared telescope before it. HST's achievements generally don't involve singular discoveries. More often, HST has taken existing hints and suspicions from ground-based observations and turned

them into certainty. In other cases, HST has provided a level of detail that forced theorists to revise previous models and construct new ones that would be consistent with the superior emerging data.



South Pacific Star Party Astrophotography Competition 2015

The Astronomical Society of NSW recently announced the winners of its annual astrophotography competition. We're pleased to present here the top three place-getters in each of the deep sky and open categories.

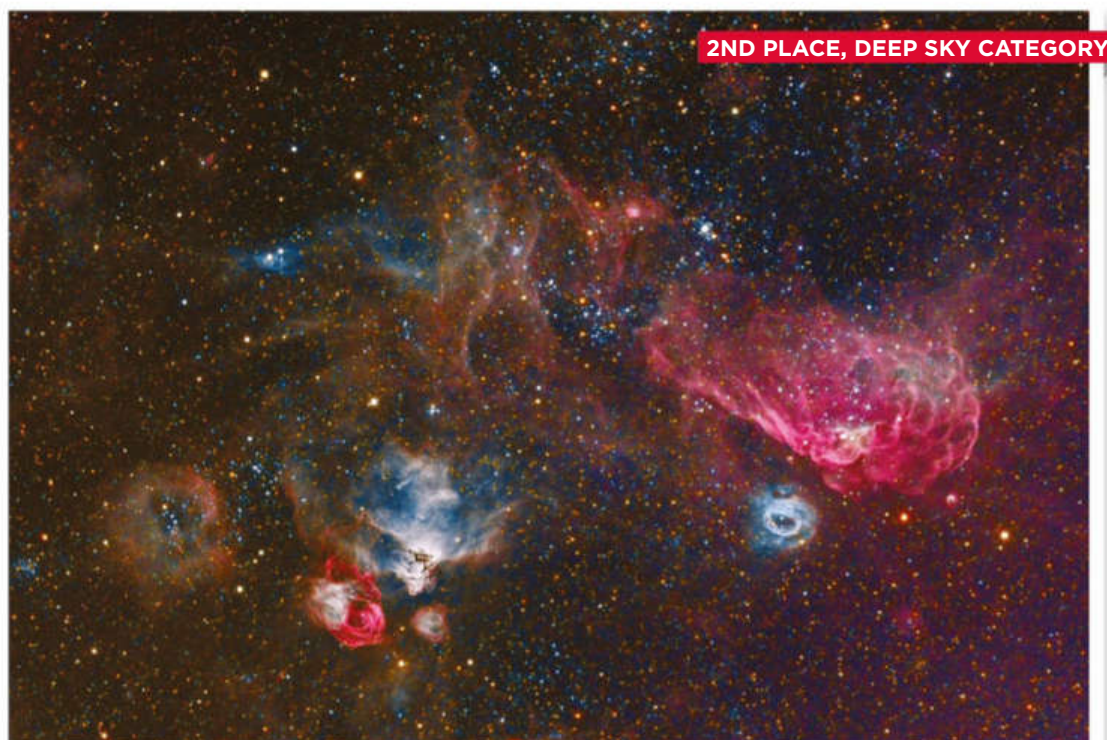


1ST PLACE, DEEP SKY CATEGORY

▲ **COSMIC PACMAN**

Mike Sidonio

CG4, a so-called cometary globule, was once beyond the reach of amateur astrophotography. But modern technology has changed the situation. Mike used a 30-cm Newtonian and cooled CCD camera with a total of 11 hours of exposure.



2ND PLACE, DEEP SKY CATEGORY

◀ THE SOUTHERN SEAGULL

Steven Mohr

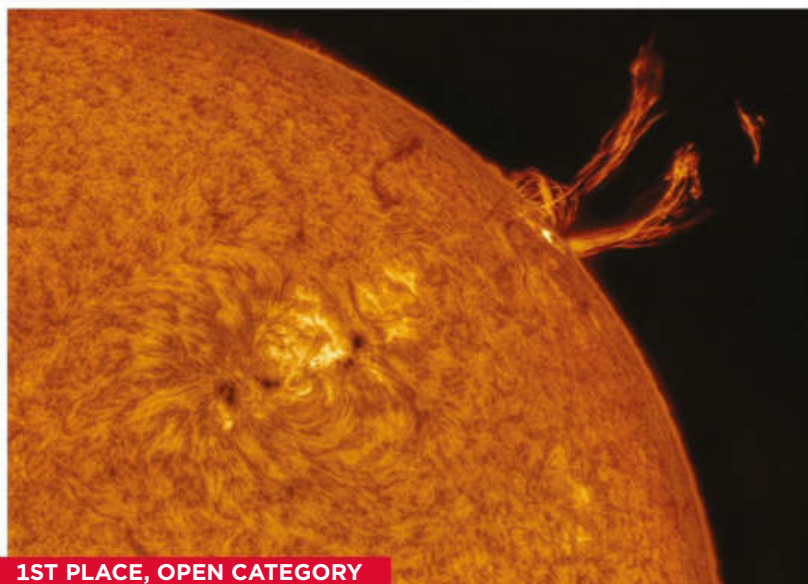
Located in the Large Magellanic Cloud, this region of nebulosity and star clusters includes NGCs 2014, 2020, 2029, 2035 and 2040. Steven used a PlaneWave CDK 12.5 telescope, Astro-Physics 900 GTO mount, SBIG STXL-1002 camera and more than 10 hours of exposure from light-polluted suburban skies.

3RD PLACE, DEEP SKY CATEGORY

▼ DUSTY HAT

Geoff Smith

The Sombrero Galaxy, 28 million light-years away, was captured using a PlaneWave CDK 12.5 telescope, Astro-Physics 900 mount, QSI 540 camera and a total exposure of 6 hours.



1ST PLACE, OPEN CATEGORY

▲ SOLAR STUNNER

Ted Dobosz

Think about this: our Earth is about 12,700km wide; the prominence seen leaping out from the solar surface in this shot, is around 220,000km long! Ted used a Sky-Watcher 100mm refractor and Basler Ace camera.

HOW TO SUBMIT YOUR IMAGES

Images should be sent electronically. Please email your contributions at contributions@skyandtelescope.com.au and provide full details of all images, eg. date and time taken; telescope and/or lens used; mount; imaging equipment type and model; filter (if used); exposure or integration time; and any software processing employed. If you have a contributed image published in *Australian Sky & Telescope*, you'll receive a 3-issue subscription or renewal to the magazine.



GALACTIC WEB

Greg Priestly

A huntsman spider 'photobombed' Greg's image of the Milky Way. The arachnid was sitting atop a Rokinon 14mm f/12.8 lens attached to a Sony A7 camera and static tripod.

EQUAL 2ND PLACE, OPEN CATEGORY



EQUAL 2ND PLACE, OPEN CATEGORY

▲ MILKY WAY

Lucas Comino

Uninterrupted by spiders, Lucas shot this image of the Milky Way using a Canon 5D.



3RD PLACE, OPEN CATEGORY

▲ COMET VS METEOR

Karen Whittingham

There's just about everything in this image: Comet Lovejoy, a meteor, countless stars, and even a few distant galaxies. Karen used a QSI 683 camera for the 5-minute exposure.

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Next Issue ON SALE

15 October



The next 'blue dot'

Researchers are developing space technology to directly image Earth-size worlds in the habitable zones of their host stars.

How to make massive stars

Astronomers are working out the recipe for some of the brightest stars in our sky.



Shooting nightscapes

Learn the best techniques to photograph your favourite landscapes crowned with the stars above

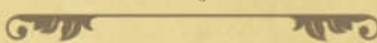
Test Report: Vixen R130S

We take a close look at a Vixen 12.7-cm Newtonian reflector and mount package.



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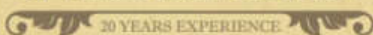
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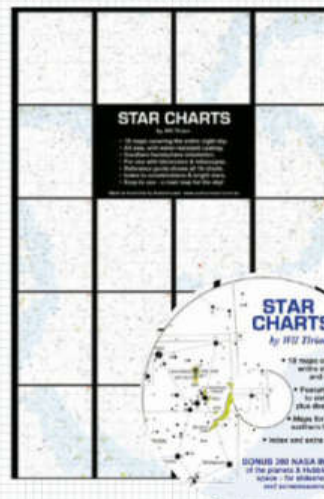
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Celestial connections

A journey that began long ago and far away, ends with the light in your eyes

Many years ago I was a Visiting Fellow at Oxford University in England researching the origins of the Julian Period, on which the Julian Day count is based. I had the run of the Bodleian Library, with its fabulous collection of medieval astronomical manuscripts. Upwards of a thousand years old, these manuscripts written on sheep- or pigskin have endured the ravages of time and the occasional (literal) bookworm. Some are bound with twine and have ancient wooden boards as covers. I felt privileged to hold and study these venerable originals. A facsimile or digital copy just could not have evoked the same wonder at the durability of the written word or offered such a tangible link spanning almost a millennium.

One can say much the same of many astronomical phenomena. Everyone knows what a total solar eclipse looks

like from seeing them in the news or in books. But it is quite another thing to actually experience a total solar eclipse yourself. You feel awe, even reverence. Watching the darkness approach and disappear with such speed, seeing the stars in the middle of the day, noticing the bewilderment of farm animals also witnessing the event — nothing can compare with it.

Similarly, watching a transit of Venus, which was I fortunate to do in both 2004 and 2012, is astounding. No photograph or news report could replace tracking that bullet hole as it migrated across the solar disk. (I hope my great-grandchildren observe the next transit in 2117. That would be a cosmic connection of a different sort, reaching across four generations.)

But you needn't wait for a rare celestial event like an eclipse or transit to experience such a bond. In a sense it happens every time you look at

the cosmos with your naked eye or through a telescope. The thin stream of photons from distant stars and galaxies transfers energy from them to you across many light-years. It's not much energy, but it's an actual cosmic link across space and time. You are seeing and experiencing history in real time. What a privilege it is altogether to detect these few primordial messengers out of the myriad photons those stellar sources emitted into space long ago.

It's an actual cosmic link across space and time. You are seeing and experiencing history in real time.

Nowadays we have CCD detectors that collect those original photon messengers and record copies for our eyes to observe. As magnificent as those images often are, we arguably lose something in the process, because that direct energy transfer from such deep-sky objects to us is broken — ironically, in the final few centimetres after travelling trillions of kilometres.

The difference between absorbing the energy from a copy rather than from the original stellar source is an ethereal but distinct one. It just isn't the same, just as it wouldn't have been the same years ago had I examined replicas of those medieval manuscripts rather than the very pages handwritten by anonymous scribes centuries before the advent of movable type. ♦

The strand of photons that reaches your eye from a distant galaxy forms a tenuous yet actual link trillions of kilometres and millions of years long. MASIL IMAGING TEAM

Ronald Lane Reese is a former Professor of Physics and author of *University Physics*, an introduction to calculus-based physics. He taught physics and astronomy for 40 years before retiring in 2011.

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